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Sedimentology, Palaeoecology and Economic Geology of Lower Colorado (Cretaceous) Strata of West-Central Saskatchewan

Frank Simpson

1982

Saskatchewan Energy and Mines

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Geological Survey

Sedimentology, Palaeoecology and Economic Geology of Lower Colorado (Cretaceous) Strata of West-Central Saskatchewan

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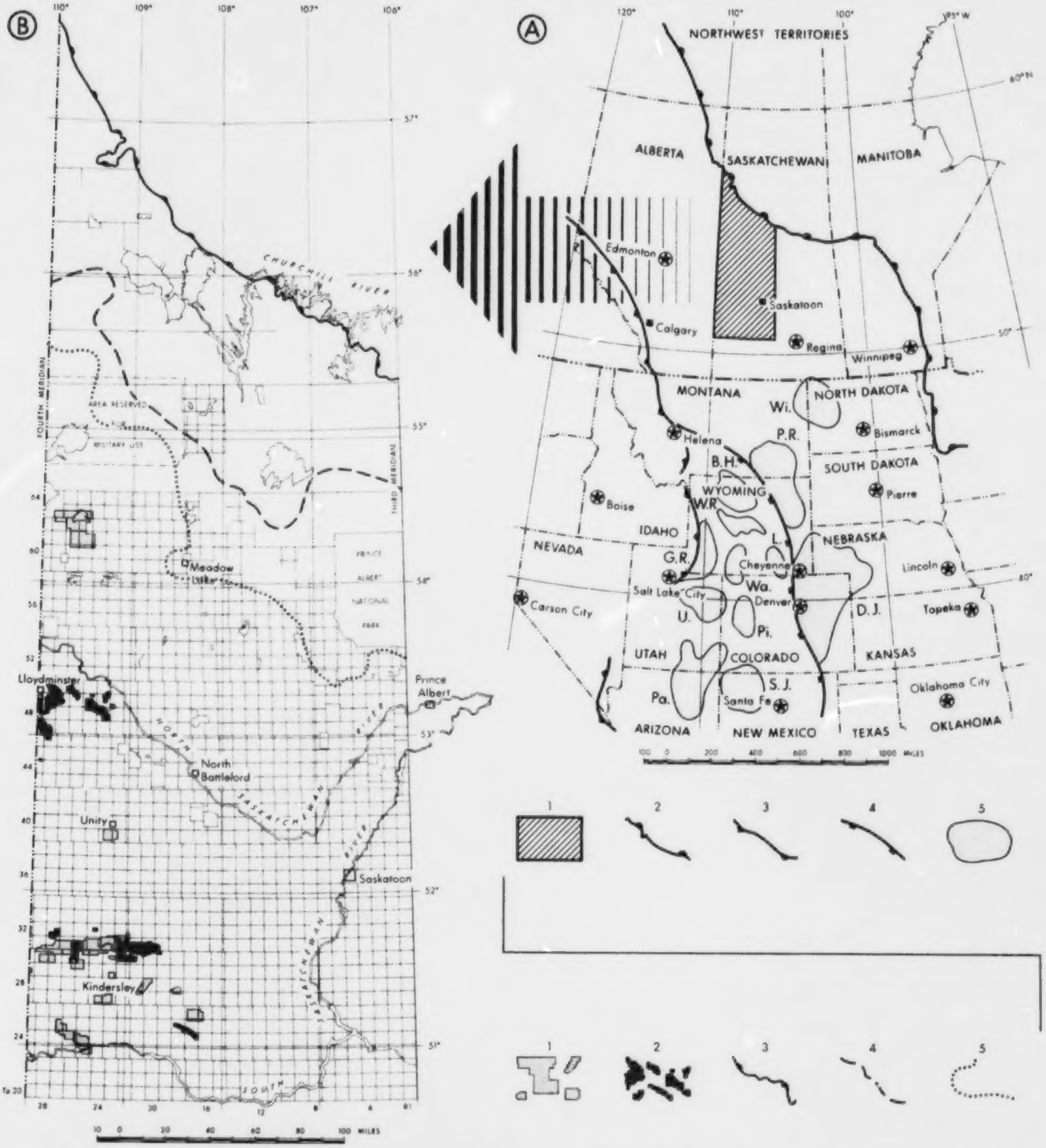
Introduction

Location

The study area is 152 750 km^2 of west-central Saskatchewan, located between the Third and Fourth Meridians and delimited in the south by the southern boundary of Township 20 and in the north by the northern limit of Lower Colorado strata (Fig. 1).



Ⓑ
110°
109°
108°
107°
106°
57°
56°
55°
54°
53°
52°
51°
CHURCHILL RIVER
FOURTH MERIDIAN
THIRD MERIDIAN
AREA RESERVED FOR MILITARY USE
PRINCE ALBERT NATIONAL PARK
Meadow Lake
Lloydminster
North Battleford
NORTH SASKATCHEWAN RIVER
Prince Albert
Unity
Saskatoon
Kindersley
SOUTH SASKATCHEWAN RIVER
SOUTH
64
60
56
52
48
44
40
36
32
28
24
Tp 20
28
24
20
16
12
8
4
R1
10 0 20 40 60 80 100 MILES
1
2
3
4
5
Ⓐ
120°
110°
100°
95° W
60° N
50°
40°
NORTHWEST TERRITORIES
ALBERTA
SASKATCHEWAN
MANITOBA
Edmonton
Calgary
Saskatoon
Regina
Winnipeg
MONTANA
NORTH DAKOTA
Wi.
P.R.
Helena
Bismarck
B.H.
SOUTH DAKOTA
WYOMING
W.R.
Pierre
Boise
IDAHO
NEVADA
G.R.
L.
NEBRASKA
Cheyenne
Lincoln
Salt Lake City
Wa.
Denver
Carson City
U.
D.J.
Topeka
Pi.
UTAH
COLORADO
KANSAS
S.J.
Pa.
Santa Fe
Oklahoma City
ARIZONA
NEW MEXICO
TEXAS
OKLAHOMA
100 0 200 400 600 800 1000 MILES
1
2
3
4
5

Figure 1 — Location map showing west-central Saskatchewan in relation to northern Great Plains region.

A — Principal structural and depositional basins of Cretaceous age in northern Great Plains region.

1 — area of detailed study; 2 — southern edge of Precambrian Shield; 3 — secondary arc of Rocky Mountains; 4 — Big Horn-Front Range series of uplifts; 5 — basin (BH — Big Horn; D-J — Denver-Julesberg; GR — Green River; L — Laramie; Pa — Paradox; Pi — Piceance; PR — Powder River; U — Uinta; Wa — Washakie; W — Williston; WR — Wind River).

B — Distribution of petroleum production in study area.

1 — gas production; 2 — oil production; 3 — southern edge of Precambrian Shield; 4 — northern limit of Lower Colorado strata; 5 — northern limit of Upper Colorado strata .

Topography and Surface Geology

Elevations are mainly in the range 300 to 750 m above sea level. Undulating to strongly rolling topography (Missouri Coteau) of the Alberta Plains yields fairly abruptly eastward to a more gently undulating steppe of lower elevation (Saskatchewan Plain and Ile-à-la-Crosse Lowland). Moraine, till, glaciolacustrine clays and silts, as well as glacio-fluvial sands and gravels constitute an extensive drift cover, reaching thicknesses of up to 275 m over pre-glacial valleys (Christiansen, 1965). Southwesterly younging sub-crops of the Cretaceous fine-grained, clastic Montana, Colorado and Mannville Groups are overlain by glacial deposits. At the Shield an intermittent belt of Devonian carbonates a few kilometres wide occurs. Scarce Colorado exposures are largely confined to river banks especially those of the South and North Saskatchewan.

Geological Setting

Colorado sediments of west-central Saskatchewan represent deposits transversely developed in a shallow, epeiric sea, continuous over the Western Interior of Canada and the United States by Cenomanian-Turonian time (Cobban and Reeside, 1952) and arising from the union of the boreal and gulfian seas when the latter crossed the divide south of Kansas (Eicher, 1960). A complex series of clastic wedges were built eastwards from the bordering western highland (Nevadan orogeny), whereas the eastern cratonic borderland, including the Canadian Shield and Siouxia arch of South Dakota and Nebraska, furnished by comparison only minor quantities of detritus (Spieker, 1946; Reeside, 1957; Weimer, 1961; Rudkin, 1964; Williams and Burk, 1964). These sediments are preserved in exogeosynclines adjacent to the Alberta-Montana disturbed belt (Alberta exogeosyncline) and the Wasatch hinge belt (Green River and Uinta exogeosynclines). They are flanked to the east by unstable shelf which is replaced southward by the isolated Williston basin and a series of yoked basins (Powder River, Big Horn, Denver, San Juan and others) with intervening intracratonic uplifts (see, for instance, Badgley, 1965, p. 480, Figs. 11-17).

The standard reference sequence for Cretaceous stratigraphic units of the Western Interior of the United States (Cobban and Reeside, 1952, Plate I, facing p. 1,011, 1,043) presents the Colorado Group (Cenomanian-Santonian) as comprising the Niobrara Formation, The Carlile Shale, the Greenhorn Limestone and the Belle Fourche Shale, in order of increasing age. Four units of Albian age, namely the Mowry Shale, the Newcastle Sandstone, the Skull Creek Shale and the Fall River Sandstone, are also listed, youngest to oldest, below the base of the Colorado Group without group designation. In the northern Great Plains region, the upper three of these latter units or their equivalents have been included with the Colorado Group by usage, and the lowermost to the underlying continental or mixed continental-marine succession.

In Saskatchewan, the Colorado Group is delimited by the Mannville Formation (Group) (Aptian-Albian) and the Lea Park Formation (Santonian-Campanian) of the Montana Group (ASPG Lexicon Committee, 1960). A division of the Colorado Group into upper and lower subgroups is made at the base of a widespread marker unit, the Second (Lower) White-Speckled Shale (Turonian). The boundary between Lower and Upper Cretaceous is taken at the base of the Fish-Scale Marker, some 18 to 30 m below the Upper Colorado. The latter boundary was drawn on the Mowry Shale by Cobban and Reeside (1952), but was lowered to within that Shale by Reeside (1957) and raised to within the Belle Fourche Shale by Cobban (1960). The main stratigraphic units of the Colorado Group in west-central Saskatchewan and selected areas in the northern Great Plains region are presented in Fig. 2.

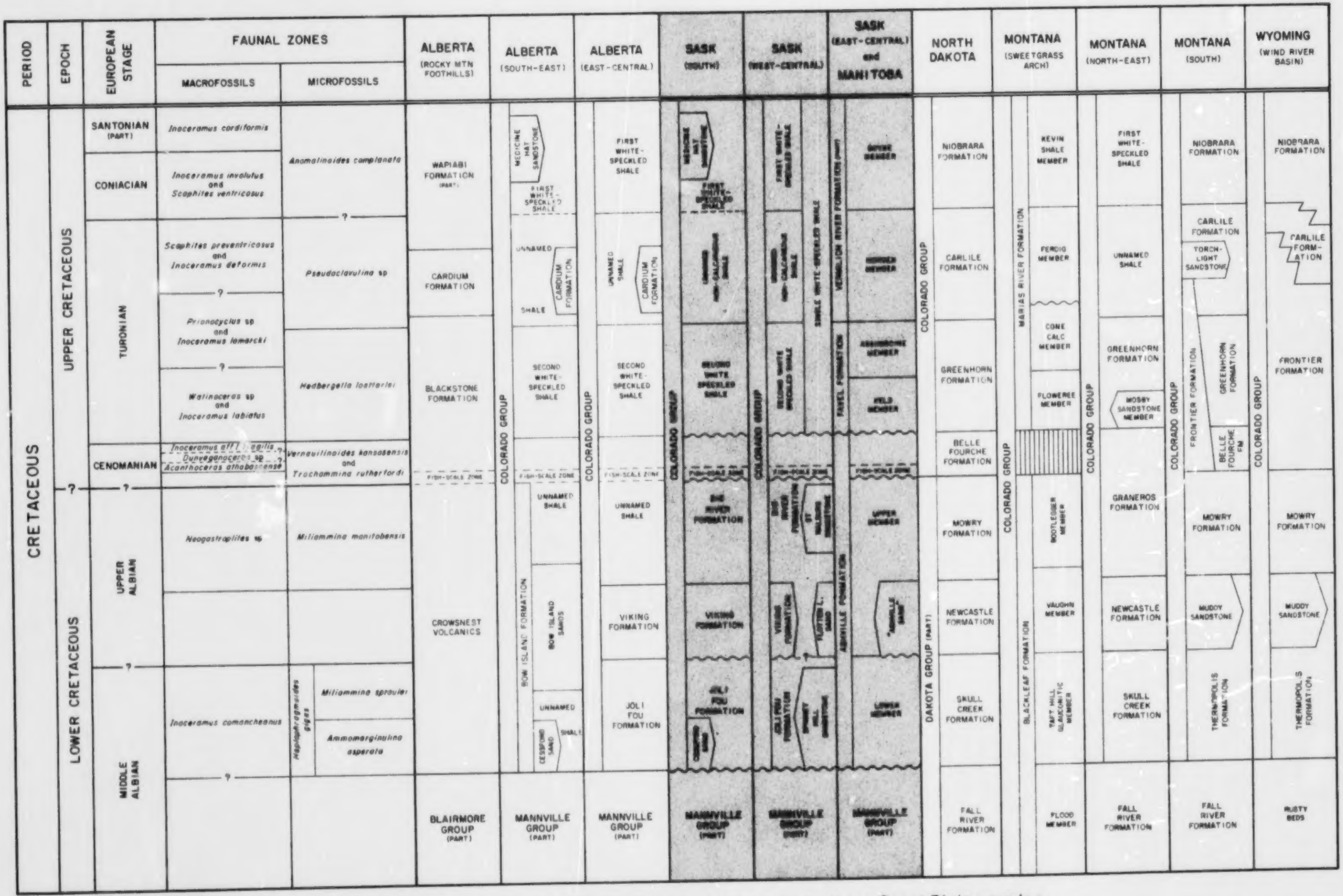

PERIOD
EPOCH
EUROPEAN STAGE
FAUNAL ZONES
MACROFOSSILS
MICROFOSSILS
ALBERTA (ROCKY MTN FOOTHILLS)
ALBERTA (SOUTH-EAST)
ALBERTA (EAST-CENTRAL)
SASK (SOUTH)
SASK (WEST-CENTRAL)
SASK (EAST-CENTRAL) and MANITOBA
NORTH DAKOTA
MONTANA (SWEETGRASS ARCH)
MONTANA (NORTH-EAST)
MONTANA (SOUTH)
WYOMING (WIND RIVER BASIN)
CRETACEOUS
UPPER CRETACEOUS
LOWER CRETACEOUS
SANTONIAN (PART)
CONIACIAN
TURONIAN
CENOMANIAN
UPPER ALBIAN
MIDDLE ALBIAN
Inoceramus cordiformis
Inoceramus involutus and Scaphites ventricosus
Scaphites preventricosus and Inoceramus deformis
Prionocyclus sp and Inoceramus lamarcki
Watinoceras sp and Inoceramus labiatus
Inoceramus aff I. gracilis
Dunveganoceras sp
Acanthoceras athabascense
Neogastroplites sp
Inoceramus comancheanus
Anomalinoides complanata
Pseudoclavulina sp
Hedbergella loetterlei
Verneuilinoides kansasensis and Trochammina rutherfordi
Miliammina manitobensis
Haplophragmoides gigas
Miliammina sproulei
Ammomarginulina asperata
WAPIABI FORMATION (PART)
CARDIUM FORMATION
BLACKSTONE FORMATION
FISH-SCALE ZONE
CROWSNEST VOLCANICS
BLAIRMORE GROUP (PART)
COLORADO GROUP
MEDICINE HAT SANDSTONE
FIRST WHITE-SPECKLED SHALE
UNNAMED SHALE
CARDIUM FORMATION
SECOND WHITE-SPECKLED SHALE
BOW ISLAND FORMATION
BOW ISLAND SANDS
UNNAMED SHALE
CESSFORD SAND
MANNVILLE GROUP (PART)
VIKING FORMATION
JOLI FOU FORMATION
UNNAMED NON-CALCAREOUS SHALE
BIG RIVER FORMATION
ST WALBURG SANDSTONE
SINGLE WHITE-SPECKLED SHALE
FLOTTEN L. SAND
SPINNEY HILL SANDSTONE
VERMILION RIVER FORMATION (PART)
FAVEL FORMATION
ASHVILLE FORMATION
BOYNE MEMBER
MORDEN MEMBER
ASSINIBOINE MEMBER
KELD MEMBER
UPPER MEMBER
"NEWCASTLE" SAND
LOWER MEMBER
NIOBRARA FORMATION
CARLILE FORMATION
GREENHORN FORMATION
BELLE FOURCHE FORMATION
MOWRY FORMATION
NEWCASTLE FORMATION
SKULL CREEK FORMATION
DAKOTA GROUP (PART)
FALL RIVER FORMATION
MARIAS RIVER FORMATION
KEVIN SHALE MEMBER
FERDIG MEMBER
CONE CALC MEMBER
FLOWEREE MEMBER
BOOTLEGGER MEMBER
VAUGHN MEMBER
TAFT HILL GLAUCONITIC MEMBER
BLACKLEAF FORMATION
FLOOD MEMBER
UNNAMED SHALE
MOSBY SANDSTONE MEMBER
GRANEROS FORMATION
TORCH-LIGHT SANDSTONE
FRONTIER FORMATION
BELLE FOURCHE FM
MUDDY SANDSTONE
THERMOPOLIS FORMATION
CARLILE FORM-ATION
RUSTY BEDS
?

Figure 2 — Correlation chart for Colorado Group and contiguous lithostratigraphic units in northern Great Plains region.

In a review of the Lower Cretaceous in the Western Canada Basin, Rudkin (1964) describes the Lower Colorado sequence as mostly argillaceous, with sandstones largely restricted to areas of greatest subsidence and deposition in the west of the region and becoming markedly thinner and finer-grained eastwards. Western uplands of the Nevadan orogeny served as the principal source of coarser-grained deposits, the eastern shore was located "at least several hundred miles east of the present eroded edge of the Lower Cretaceous beds" (Rudkin, *loc. cit.*, p. 167). However, in west-central Saskatchewan, the entire Lower Colorado sequence exhibits considerable lateral variation, such that the argillaceous Joli Fou and Big River Formations display northerly and north-easterly increase in sand content. In contrast the sandy Viking Formation attenuates to the north-east, until it can no longer be distinguished (Simpson, in Christopher *et al*, 1971). Thus the Shield is considered to have undergone epeirogenic uplift, being then the source of these eastern sands and the eastern shoreline thus to have been located only tens of kilometres to the east of the present edge of Lower Cretaceous strata, rather than hundreds.

Facies in the lower part of the Colorado sequence vary from the southern foothills of the Canadian Rocky Mountains northeastward to the erosional edge of the Group in central Saskatchewan (Fig. 3). This variation conveniently expressed as facies associations in three belts, subparallel to the miogeosyncline.

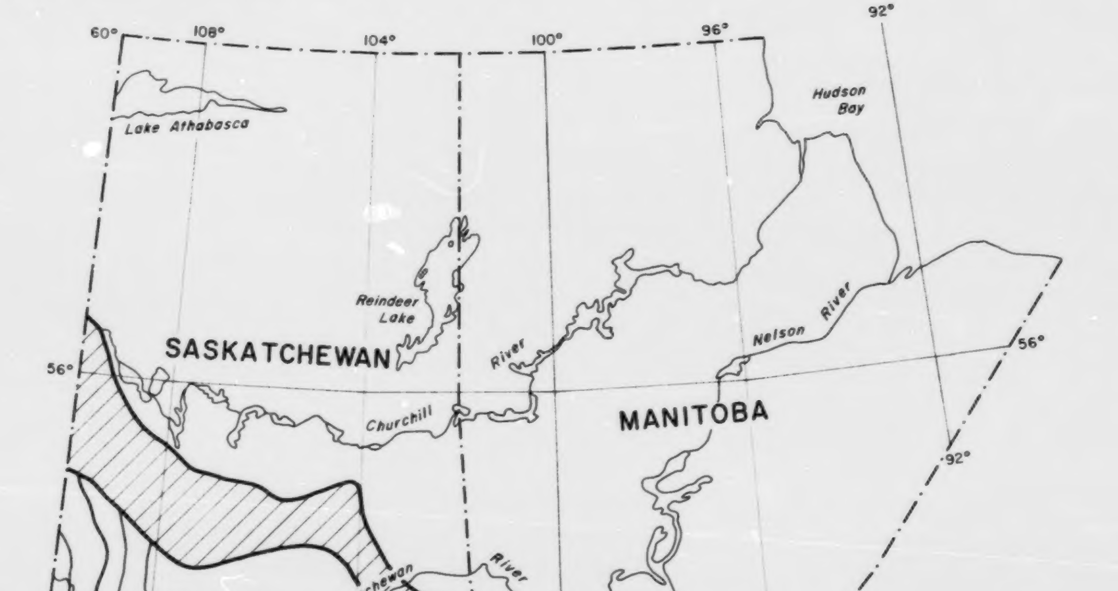

60°
108°
104°
100°
96°
92°
Lake Athabasca
Hudson Bay
Reindeer Lake
SASKATCHEWAN
River
Churchill
Nelson
River
56°
MANITOBA
River
Saskatchewan
North
South
Lake Winnipeg
Lake Winnipegosis
Lake Manitoba
SASKATOON
REGINA
WINNIPEG
52°
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
Isopach interval: 100 feet
Outcrop area
Credits:
Rudkin, 1964
Williams and Burk, 1964
Scale in Miles
50
0
50
100
150

Figure 3 — Isopach map of the Colorado Group in Saskatchewan and Manitoba.

(1) In the arenaceous *inner zone* flanking the Foothills, three main Bow Island sand units and intervening mudstones and siltstones, occupy the interval between the sandy Fish-Scale Marker and the Mannville Formation (Glaister, 1959), reaching a maximum thickness of nearly 180 m. To the southwest, the Bow Island facies is incorporated with the upper part of the Blairmore Group, but to the northeast it thins into Viking lenticular sand bodies separating two thick mudstone units (Gammell, 1955). Basal Colorado sands, such as the Cessford sand, are also present but have a restricted development.

(2) A predominantly argillaceous *central zone* is characterized by extensive mudstones above and below the Viking Formation, as well as by attenuation and pinching out of the Viking. Other sands, including the basal Spinney Hill increase northward even though the lithotope as a whole thins from over 150 m to less than 90 m.

(3) A discontinuous, northward thickening, largely arenaceous *marginal zone* follows the erosional edge of the Colorado. It includes the St. Walburg Sandstone, Flotten Lake Sand and Spinney Hill Sandstone.

Scope of Study

This report is largely a stratigraphic-sedimentological study of the Lower Colorado in the subsurface of west-central Saskatchewan. Interpretations are based largely on (1) the geometry of 9 principal electric log correlation surfaces, (Appendix A), and (2) detailed descriptions of cores (Simpson, 1979). Those data were augmented by that from seismic test holes and water wells in the north, where well control is relatively poor.

Lithologies seen in core are described and interpreted in terms of a scheme relating gross lithologic type to a restricted number of associations of sedimentary structures. In the light of experimental work on sedimentation and studies of Recent sediments, these relationships provide the basis for recognition of ancient shallow-water, marine environments. These findings are supported by a palaeoecological study of sedimentary layer properties in associations with biogenic structures. The foregoing is important in the determination and extrapolation of sand-body trends, especially those with good reservoir characteristics.

Physical and chemical characteristics of formation fluids are briefly discussed in relation to sedimentary layer properties, patterns of facies distribution and large-scale structural features. Hydrocarbon prospects and problems of primary recovery and water supply systems in the north are considered on the basis of the distribution of particular formation fluids.

Acknowledgements

It is a great pleasure to here acknowledge help from a number of workers in Saskatchewan Department of Mineral Resources. J. E. Christopher and D. F. Paterson edited the manuscript and contributed helpful discussion. J. E. Christopher offered greatly appreciated comments on ideas developed at various stages of the project. A. C. Kendall discussed aspects of diagenesis relevant to the present account. P. L. Broughton carried out several X-ray diffractometry determinations. D. R. Gillard, P. Guliov, G. F. Hutch and K. H. von Ledebur also helped in various ways. Figures were prepared for publication under the supervision of J. Toews, D. F. Clausen and R. P. Kydd. The author also acknowledges helpful conversations with many geologists of the oil industry. Particular thanks are due to the late R. L. Milner, who kindly discussed the distribution of Lower Colorado sands in the Prince Albert region. All information relating to Colorado sediments of the Duval Saskatoon 6-18-32-6 well (Lsd 6-18-32-6W3) appears by permission of the Duval Corporation.

Stratigraphy

Colorado Group

The Colorado Group (middle Albian to Santonian) has its type section in Colorado and covers a wide area of the Western Interior of North America. In general it is dominantly argillaceous (ASPG Lexicon Committee, 1960; Balster, 1971), and incorporates subordinate shaly conglomerate, sandstone and siltstone, as well as minor shaly chalk, chalky limestone, bentonite, pelecypod coquinas, accumulations of fish-skeletal debris, nodular phosphorite and concretionary layers of calcite, siderite and pyrite. The Colorado Group is divisible into an upper, calcareous and a lower, non-calcareous part, at the base of the lower of two widespread marker units, the First (Upper) and Second (Lower) White-Speckled Shale. The white-speckled shales are characterized by abundant, white flakes of coccolithic debris and, together with an intervening, unnamed sequence of non-calcareous shale, make up the Upper Colorado. Each of the Upper Colorado units incorporates one or more sandstones of restricted distribution: the Phillips (Second White Specks) Sandstone of the Second White-Speckled Shale; the Bowdoin and Cardium Sandstones of the unnamed, non-calcareous shale; and the Martin Sandy Zone and Medicine Hat Sandstone of the First White-Speckled Shale. The Lower Colorado comprises upper and lower, non-calcareous shale units — The Big River and Joli Fou Formations respectively — separated by a prominent, northeastward-thinning wedge of coarse, siliciclastic strata, the Bow Island-Viking. The Big River shales include the widespread Fish-Scale Marker, which consists of fish-skeletal debris in shaly sands spanning the Lower-Upper Cretaceous boundary. Both the Big River and Joli Fou Formations are replaced northeastwards by the St. Walburg and Spinney Hill Sandstones respectively. The Lower Colorado sequence remains undifferentiated, where the Bow Island-Viking strata and its northern equivalents, the Pelican Sandstone and Flotten Lake Sand, are absent.

The Colorado Group is recognized across central and southern Alberta and the western half of Saskatchewan. It is best known from subsurface data, although scattered exposures are found, notably along the northeastern erosional edge. Maximum thicknesses exceed 1,000 m in southern Alberta, whereas minimum values for the complete succession are in the order of 150 m in central Saskatchewan.

The Colorado underlies the Montana Group and overlies the Dakota Group in the type area along the east of the Front Range in Colorado. In western Canada, the Colorado Group is unconformably overlain by the Lea Park Shale, which forms the basal unit of the Montana Group throughout much of the region except that in southwestern locations the basal Milk River Sandstone appears to grade into the Colorado Group. The Colorado rests unconformably on sandstones of the Mannville and Swan River. In southern Manitoba and eastern Saskatchewan, the Lower Colorado is named the Ashville Formation, and the upper and lower calcareous markers are the Boyne Member of the Vermilion River Formation and the Favel Formation respectively; the Morden Member of the Vermilion River Formation corresponds to the unnamed, non-calcareous shale. In the Rocky Mountain foothills of Alberta, the units (o-y) corresponding to the Colorado Group are the Crowsnest Volcanics, Blackstone Formation, Cardium Formation, and lower part of the Wapiabi Formation. The Alberta Shale of central Alberta includes the Colorado Group and Lea Park Shale.

The nomenclature of the Colorado Group in west-central Saskatchewan is summarized in Fig. 4. Stratigraphic analysis of the Lower Colorado is complicated by the dominantly gradational relationships between sandstone bodies and the enveloping mudstones and shales. These relationships are illustrated in the stratigraphic cross-sections of Figs. 5 and 6; the former demonstrates the southward and southwestward thickening of the Bow Island-Viking strata and the latter the northward and northeastward thickening of the Lower Colorado sandstones.

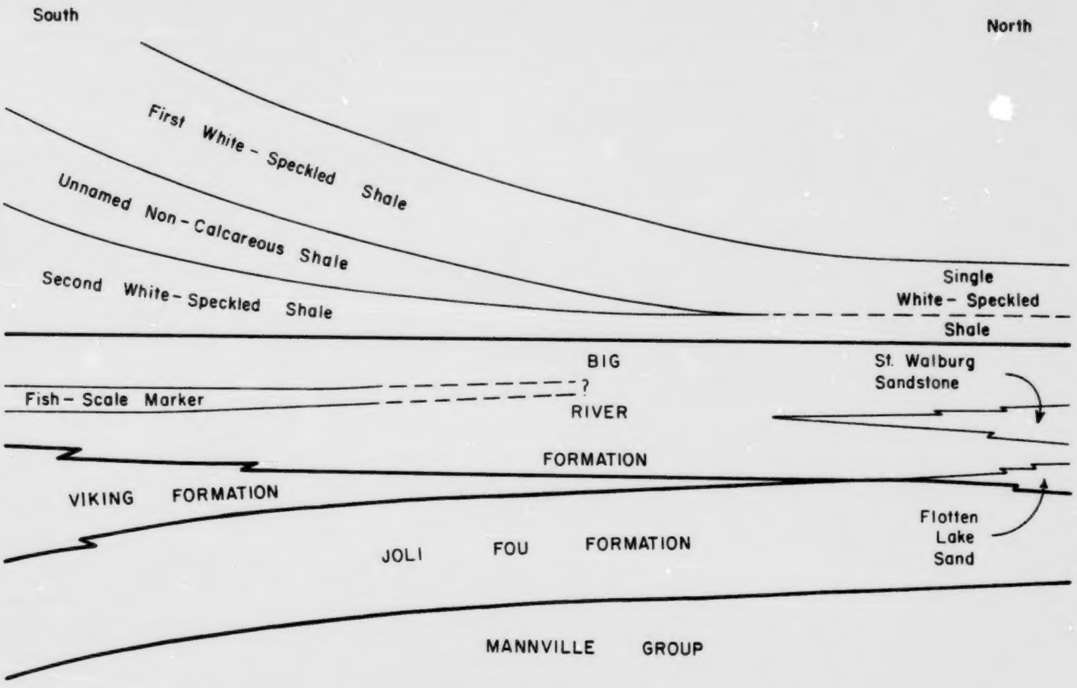

South
North
First White - Speckled Shale
Unnamed Non - Calcareous Shale
Second White - Speckled Shale
Single White - Speckled Shale
BIG
?
RIVER
FORMATION
Fish - Scale Marker
St. Walburg Sandstone
VIKING FORMATION
JOLI FOU FORMATION
Flotten Lake Sand
MANNVILLE GROUP

Figure A

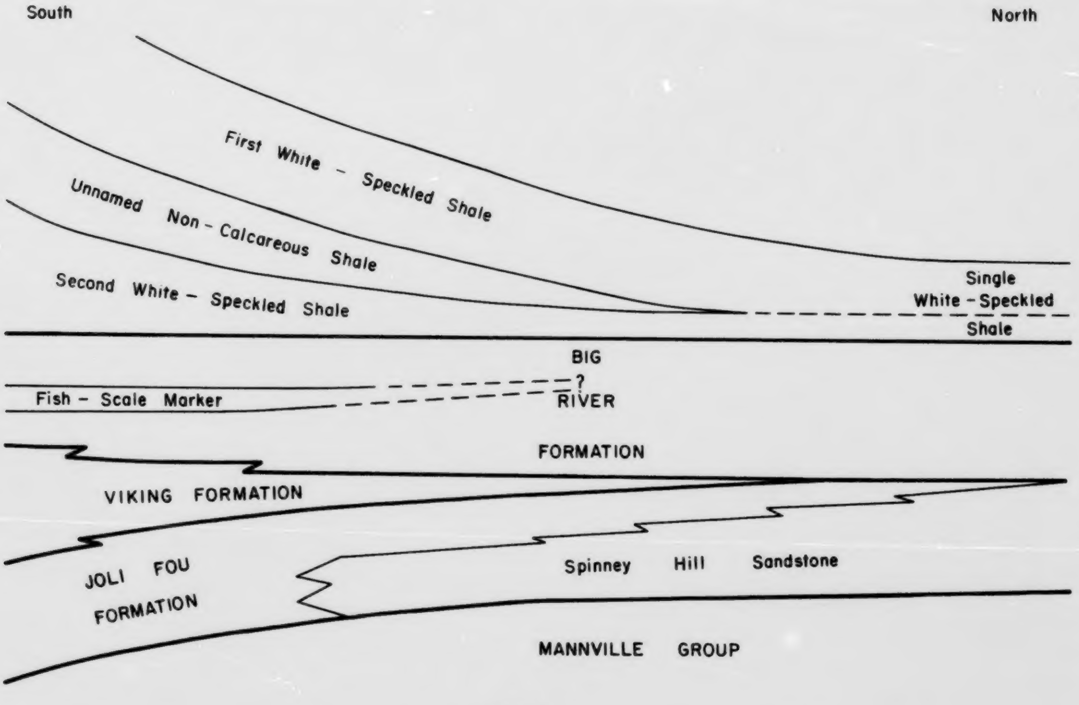

South
North
First White - Speckled Shale
Unnamed Non - Calcareous Shale
Second White - Speckled Shale
Single White - Speckled Shale
BIG
?
RIVER
FORMATION
Fish - Scale Marker
VIKING FORMATION
JOLI FOU FORMATION
Spinney Hill Sandstone
MANNVILLE GROUP

Figure B

Figure 4 — Nomenclature for subdivisions of the Colorado Group in west-central Saskatchewan. A — northwest. B — southeast.

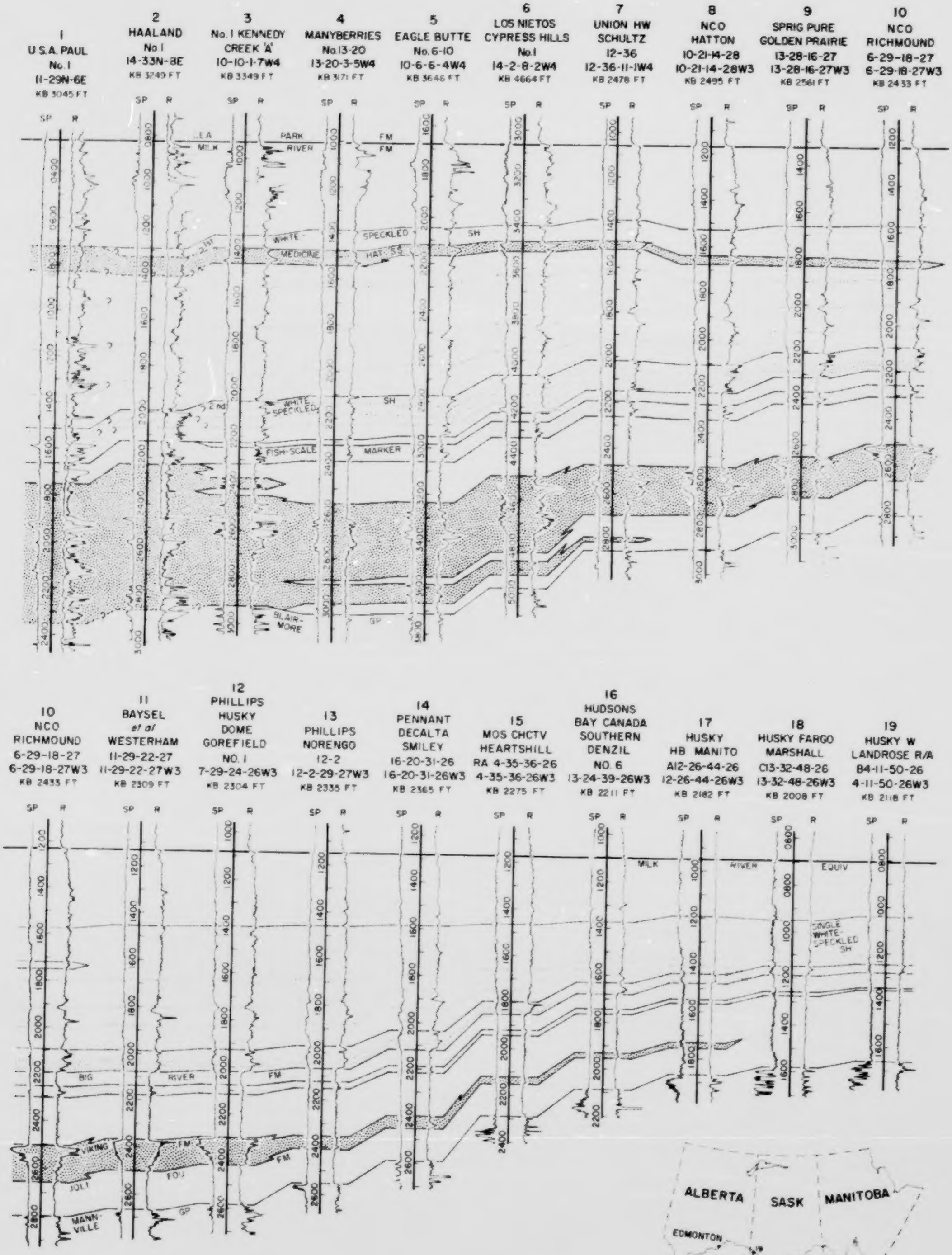

1
U.S.A. PAUL
No. 1
11-29N-6E
KB 3045 FT
2
HAALAND
No 1
14-33N-8E
KB 3249 FT
3
No. 1 KENNEDY
CREEK 'A'
10-10-1-7W4
KB 3349 FT
4
MANYBERRIES
No.13-20
13-20-3-5W4
KB 3171 FT
5
EAGLE BUTTE
No. 6-10
10-6-6-4W4
KB 3646 FT
6
LOS NIETOS
CYPRESS HILLS
No.1
14-2-8-2W4
KB 4664 FT
7
UNION HW
SCHULTZ
12-36
12-36-11-1W4
KB 2478 FT
8
NCO
HATTON
10-21-14-28
10-21-14-28W3
KB 2495 FT
9
SPRIG PURE
GOLDEN PRAIRIE
13-28-16-27
13-28-16-27W3
KB 2561 FT
10
NCO
RICHMOUND
6-29-18-27
6-29-18-27W3
KB 2433 FT
SP
R
LEA PARK FM
MILK RIVER FM
2nd WHITE SPECKLED SH
MEDICINE HAT SS
2nd WHITE SPECKLED SH
FISH SCALE MARKER
BLAIRMORE GP
10
NCO
RICHMOUND
6-29-18-27
6-29-18-27W3
KB 2433 FT
11
BAYSEL
et al
WESTERHAM
11-29-22-27
11-29-22-27W3
KB 2309 FT
12
PHILLIPS
HUSKY
DOME
GOREFIELD
NO. 1
7-29-24-26W3
KB 2304 FT
13
PHILLIPS
NORENGO
12-2
12-2-29-27W3
KB 2335 FT
14
PENNANT
DECALTA
SMILEY
16-20-31-26
16-20-31-26W3
KB 2365 FT
15
MOS CHCTV
HEARTSHILL
RA 4-35-36-26
4-35-36-26W3
KB 2275 FT
16
HUDSONS
BAY CANADA
SOUTHERN
DENZIL
NO. 6
13-24-39-26W3
KB 2211 FT
17
HUSKY
HB MANITO
A12-26-44-26
12-26-44-26W3
KB 2182 FT
18
HUSKY FARGO
MARSHALL
C13-32-48-26
13-32-48-26W3
KB 2008 FT
19
HUSKY W
LANDROSE R/A
B4-11-50-26
4-11-50-26W3
KB 2118 FT
MILK RIVER EQUIV
SINGLE WHITE SPECKLED SH
BIG RIVER FM
VIKING FM
JOLI FOU FM
MANNVILLE GP
ALBERTA
SASK
MANITOBA
EDMONTON
REGINA
WINNIPEG
HELENA
N.D.
BISMARCK
MONTANA
S.D.
PIERRE
SCALE IN MILES
100 0 100 200

Figure 5 — Stratigraphic cross-section of the Colorado Group, northwestern Montana, southeastern Alberta and western Saskatchewan.

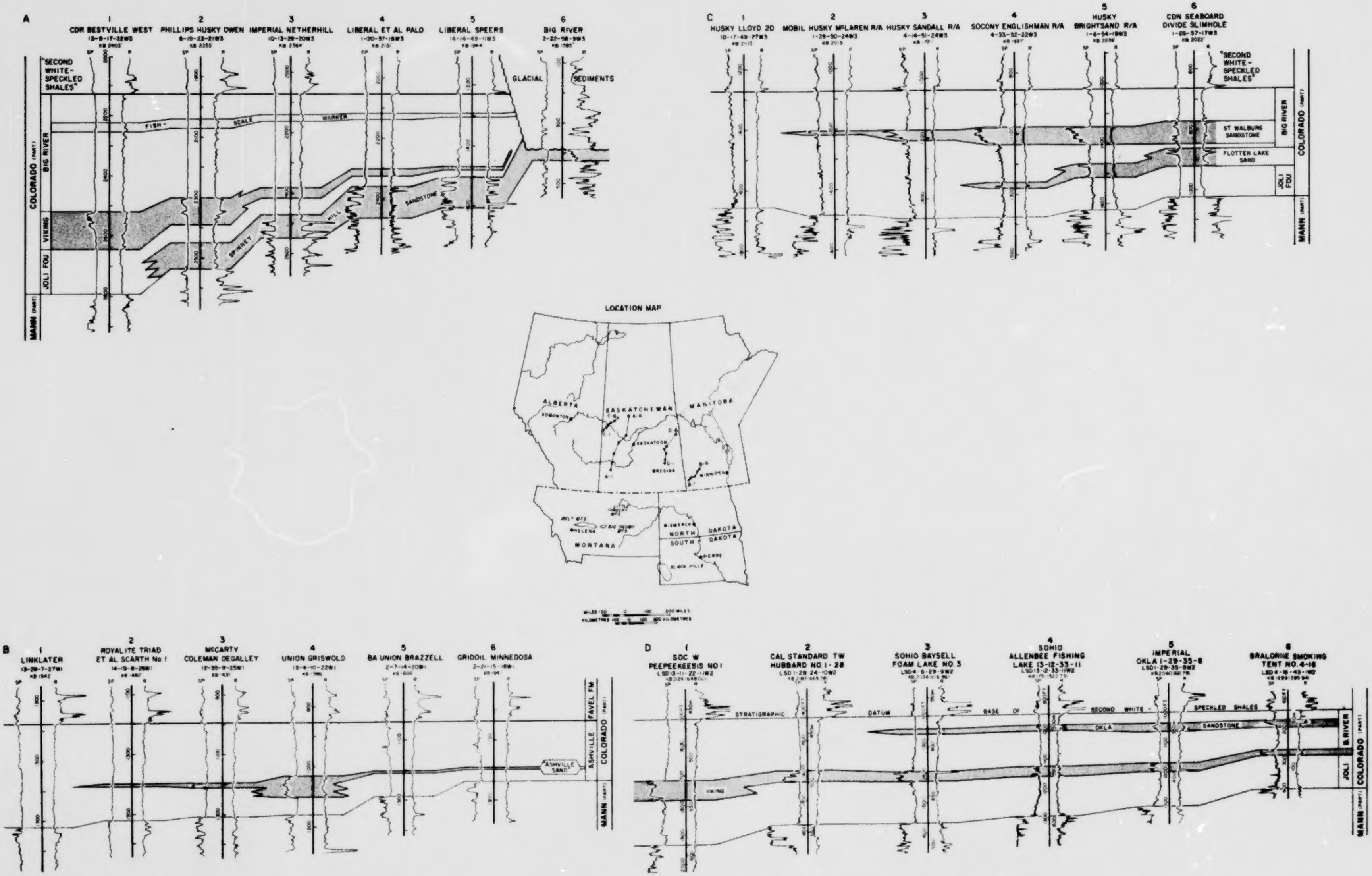

A
1 CDR BESTVILLE WEST 13-9-17-22W3
2 PHILLIPS HUSKY OWEN 6-15-22-21W3
3 IMPERIAL NETHERHILL 10-13-29-20W3
4 LIBERAL ET AL PALO 1-20-37-16W3
5 LIBERAL SPEERS 14-14-43-11W3
6 BIG RIVER 2-22-56-9W3
"SECOND WHITE-SPECKLED SHALES"
GLACIAL SEDIMENTS
FISH-SCALE MARKER
SPINNEY HILL SANDSTONE
COLORADO (PART)
BIG RIVER
VIKING
JOLI FOU
MANN (PART)
C
1 HUSKY LLOYD 2D 10-17-49-27W3
2 MOBIL HUSKY McLAREN R/A 1-29-50-24W3
3 HUSKY SANDALL R/A 4-14-51-24W3
4 SOCONY ENGLISHMAN R/A 4-33-52-22W3
5 HUSKY BRIGHTSAND R/A 1-6-54-19W3
6 CDN SEABOARD DIVIDE SLIMHOLE 1-28-57-17W3
"SECOND WHITE-SPECKLED SHALES"
ST WALBURG SANDSTONE
FLOTTEN LAKE SAND
LOCATION MAP
ALBERTA
SASKATCHEWAN
MANITOBA
EDMONTON
SASKATOON
REGINA
WINNIPEG
MONTANA
NORTH DAKOTA
SOUTH DAKOTA
BISMARCK
PIERRE
HELENA
BLACK HILLS
MILES 100 0 100 200 MILES
KILOMETRES 100 0 100 200 KILOMETRES
B
1 LINKLATER 13-29-7-27W1
2 ROYALITE TRIAD ET AL SCARTH No 1 14-19-8-26W1
3 McCARTY COLEMAN DEGALLEY 12-35-9-25W1
4 UNION GRISWOLD 13-4-10-22W1
5 BA UNION BRAZZELL 2-7-14-20W1
6 GRIDOIL MINNEDOSA 2-21-15-18W1
"ASHVILLE SAND"
FAVEL FM
ASHVILLE
D
1 SOC W PEEPEEKEESIS NO 1 LSD 13-11-22-11W2
2 CAL STANDARD TW HUBBARD NO 1-28 LSD 1-28-24-10W2
3 SOHIO BAYSELL FOAM LAKE NO. 3 LSD 4-6-29-9W2
4 SOHIO ALLENBEE FISHING LAKE 13-12-33-11 LSD 13-12-33-11W2
5 IMPERIAL OKLA 1-29-35-8 LSD 1-29-35-8W2
6 BRALORNE SMOKING TENT NO. 4-16 LSD 4-16-43-11W2
STRATIGRAPHIC DATUM BASE OF SECOND WHITE-SPECKLED SHALES
OKLA SANDSTONE
VIKING
B. RIVER

Figure 6 — Stratigraphic cross-sections of Lower Colorado sandstone bodies of the eastern shelf, Saskatchewan and Manitoba. A — Spinney Hill Sandstone, B — Ashville Sand, C — Flotten Lake Sand and St. Walburg Sandstone, D — Okla Sandstone.

Lower Colorado lithostratigraphic units of this account are essentially those used by the Saskatchewan Department of Mineral Resources; names are added to permit discussion of the poorly known sands in the north of the study area:

Sediments of the Mannville Group in places grade into those of the basal Colorado over an interval of 6 m (Maycock, 1967). Since it is probable that the various lithologies belonging to his "transition beds" are products of erosion of Mannville sediments, these are included in the Colorado sequence without formalized designation. Furthermore, a thin basal Colorado conglomerate comprising chert pebbles and clasts of eroded Mannville sediment was noted in some cores. Nonetheless, the Mannville/Colorado boundary marks the passage from a largely sandy sequence to a predominantly argillaceous one. On electric logs this is generally taken as the top of the first pronounced shoulder, marking the change to the general subdued resistivity responses of the Colorado mudstones.

The exception to this occurs in the southeast of the area where the Mannville is overlain by the Spinney Hill Sandstone. This unit is green, with abundant mudstone intercalations, and is characterized by strong, serrated and often symmetrical resistivity and spontaneous-potential signatures. Farther north, where mudstone is subordinate within the Colorado as a whole, the Spinney Hill sands account for virtually all of the Joli Fou though they remain separated from the Mannville by 3 to 8 m of mudstone (Edwards, 1960). An uppermost Spinney Hill shoulder is seen on electrical well logs throughout most of the area, although arbitrary cut-off largely restricts the Spinney Hill proper to the east. In the southwestern part of the study area, a pronounced increase in sand content of the uppermost Joli Fou Formation is also seen.

The Viking Formation comprises drab conglomerates, sandstones and siltstones with intercalated mudstones, and varies in thickness from about 43 m in the southwest of the study area to zero south of the North Saskatchewan River. The northerly and northeasterly decrease in sand content is reflected in the resistivity responses which vary from strong, serrated peaks, tapering downward and characteristic for the thicker sands in the south, to little more than weak, individual kicks in the north. The lower contact of the formation is generally taken at the base of a sandstone or conglomerate signature, though a basal silty mudstone is locally observed (Jones, 1961a). The upper limit of the formation is taken at the top of a thin siltstone signature, located some distance above the main, sandy or silty part of the unit (Jones, *loc. cit.*). The spontaneous-potential response of the Viking sequence is regarded as unreliable, because of its great variability.

The Flotten Lake Sand is the name given to a poorly known unit of sand, sandstone and intercalated mudstone restricted to the northern part of the study area. It appears to be a stratigraphic equivalent of the Viking Formation, in that it separates the Big River and Joli Fou sequences in the northern part of the area. It thins southward and grain size decreases into mudstone.

The Big River Formation is largely made up of mudstones with subordinate intercalations of drab sandstones and siltstones in the south. There it is reflected by subdued resistivity and spontaneous-potential responses, interrupted by minor kicks indicative of thin siltstones and fine-grained sandstones. The top of the formation is defined by the base of a strong positive response on spontaneous-potential, resistivity and radioactivity logs, marking the calcareous Second Speckled Shale. The lower contact is on the Viking Formation or the Flotten Lake Sand or, where neither is present, the Joli Fou Formation. One of the more persistent siltstone intercalations is the Fish-Scale Marker, which occurs some 18 to 27 m below the formation top and thins markedly northward to near extinction on well logs. In the north of the study area, the St. Walburg Sandstone occurs beneath the Fish-Scale Marker as sandstones, siltstones and mudstones (Buller and Ledebur, 1962), tongueing southward into Big River mudstones and shales. The St. Walburg is characterized by low resistivity and strong, serrated spontaneous-potential responses.

The gradational nature of the strata noted above is illustrated in the geophysical log stratigraphic cross-sections of Figs. 7 to 14 and the areal distribution of the sandy units is depicted in Fig. 15.

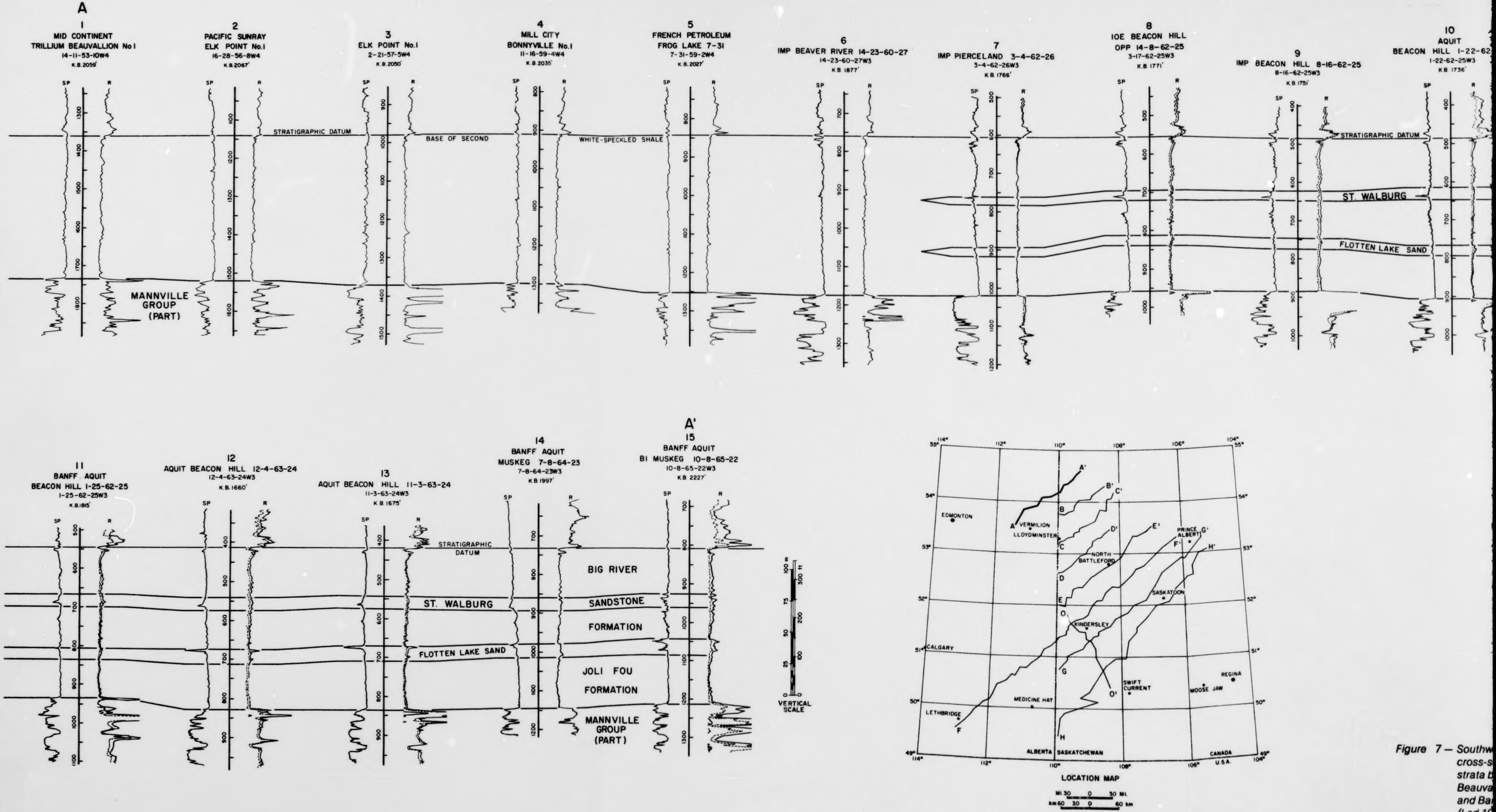
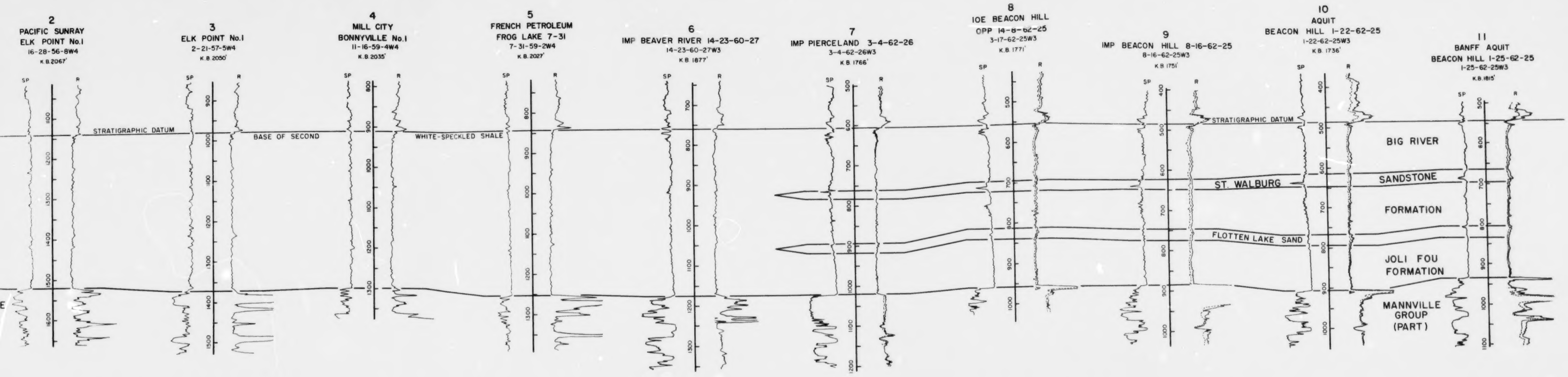
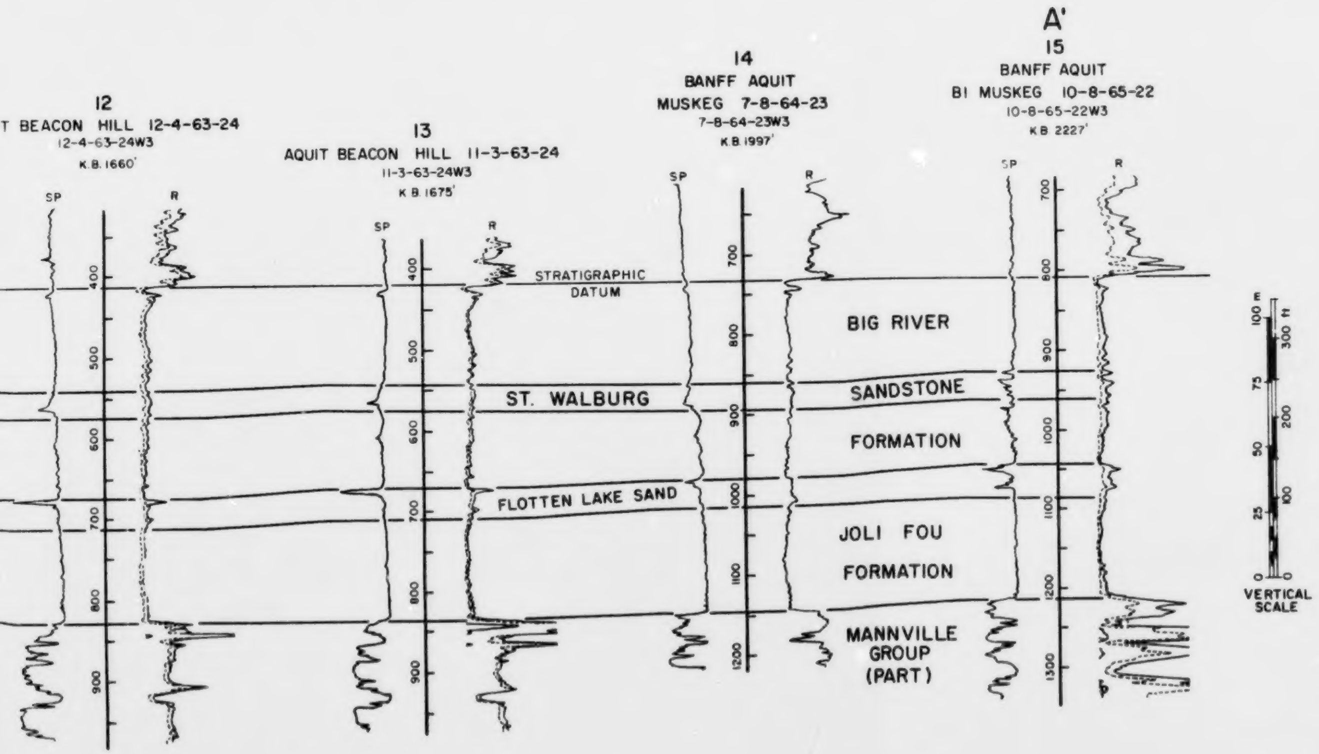

A
1
MID CONTINENT
TRILLIUM BEAUVALLION No I
14-11-53-10W4
K.B.2059'
2
PACIFIC SUNRAY
ELK POINT No.I
16-28-56-8W4
K.B.2067'
3
ELK POINT No.I
2-21-57-5W4
K.B.2050'
4
MILL CITY
BONNYVILLE No.I
11-16-59-4W4
K.B.2035'
5
FRENCH PETROLEUM
FROG LAKE 7-31
7-31-59-2W4
K.B.2027'
6
IMP BEAVER RIVER 14-23-60-27
14-23-60-27W3
K.B.1877'
7
IMP PIERCELAND 3-4-62-26
3-4-62-26W3
K.B.1766'
8
IOE BEACON HILL
OPP 14-8-62-25
3-17-62-25W3
K.B.1771'
9
IMP BEACON HILL 8-16-62-25
8-16-62-25W3
K.B.1751'
10
AQUIT
BEACON HILL 1-22-62
1-22-62-25W3
K.B.1736'
SP
R
STRATIGRAPHIC DATUM
BASE OF SECOND
WHITE-SPECKLED SHALE
ST. WALBURG
FLOTTEN LAKE SAND
MANNVILLE
GROUP
(PART)
11
BANFF AQUIT
BEACON HILL 1-25-62-25
1-25-62-25W3
K.B.1615'
12
AQUIT BEACON HILL 12-4-63-24
12-4-63-24W3
K.B.1660'
13
AQUIT BEACON HILL 11-3-63-24
11-3-63-24W3
K.B.1675'
14
BANFF AQUIT
MUSKEG 7-8-64-23
7-8-64-23W3
K.B.1997'
A'
15
BANFF AQUIT
BI MUSKEG 10-8-65-22
10-8-65-22W3
K.B.2227'
STRATIGRAPHIC
DATUM
BIG RIVER
ST. WALBURG
SANDSTONE
FORMATION
FLOTTEN LAKE SAND
JOLI FOU
FORMATION
MANNVILLE
GROUP
(PART)
100 m
75
50
25
0
300 ft.
200
100
0
VERTICAL
SCALE
114°
112°
110°
108°
106°
104°
55°
54°
53°
52°
51°
50°
49°
EDMONTON
VERMILION
LLOYDMINSTER
NORTH
BATTLEFORD
PRINCE
ALBERT
SASKATOON
KINDERSLEY
CALGARY
MEDICINE HAT
SWIFT
CURRENT
MOOSE JAW
REGINA
LETHBRIDGE
A
A'
B
B'
C
C'
D
D'
E
E'
F
F'
G
G'
H
H'
O
O'
ALBERTA
SASKATCHEWAN
CANADA
U.S.A.
LOCATION MAP
MI.30 0 30 MI.
km 60 30 0 60 km

Figure 7 — Southw
cross-s
strata b
Beauva
and Ba
(Lsd 10


2
PACIFIC SUNRAY
ELK POINT No.1
16-28-56-8W4
K.B.2067'
3
ELK POINT No.1
2-21-57-5W4
K.B.2050'
4
MILL CITY
BONNYVILLE No.1
11-16-59-4W4
K.B.2035'
5
FRENCH PETROLEUM
FROG LAKE 7-31
7-31-59-2W4
K.B.2027'
6
IMP BEAVER RIVER 14-23-60-27
14-23-60-27W3
K.B.1877'
7
IMP PIERCELAND 3-4-62-26
3-4-62-26W3
K.B.1766'
8
IOE BEACON HILL
OPP 14-8-62-25
3-17-62-25W3
K.B.1771'
9
IMP BEACON HILL 8-16-62-25
8-16-62-25W3
K.B.1751'
10
AQUIT
BEACON HILL 1-22-62-25
1-22-62-25W3
K.B.1736'
11
BANFF AQUIT
BEACON HILL 1-25-62-25
1-25-62-25W3
K.B.1815'
SP
R
STRATIGRAPHIC DATUM
BASE OF SECOND
WHITE-SPECKLED SHALE
BIG RIVER
SANDSTONE
ST. WALBURG
FORMATION
FLOTTEN LAKE SAND
JOLI FOU
FORMATION
MANNVILLE
GROUP
(PART)


A'
12
BEACON HILL 12-4-63-24
12-4-63-24W3
K.B.1660'
13
AQUIT BEACON HILL 11-3-63-24
11-3-63-24W3
K.B.1675'
14
BANFF AQUIT
MUSKEG 7-8-64-23
7-8-64-23W3
K.B.1997'
15
BANFF AQUIT
B1 MUSKEG 10-8-65-22
10-8-65-22W3
K.B.2227'
SP
R
STRATIGRAPHIC DATUM
BIG RIVER
SANDSTONE
ST. WALBURG
FORMATION
FLOTTEN LAKE SAND
JOLI FOU
FORMATION
MANNVILLE
GROUP
(PART)
100 m
300 ft
VERTICAL SCALE

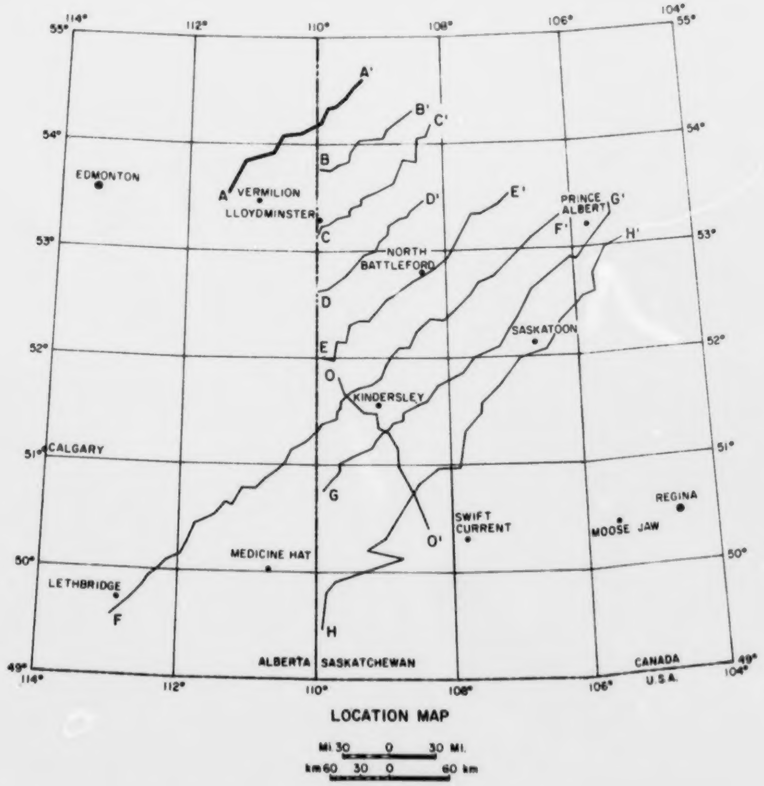

EDMONTON
VERMILION
LLOYDMINSTER
NORTH BATTLEFORD
PRINCE ALBERT
SASKATOON
KINDERSLEY
CALGARY
SWIFT CURRENT
MOOSE JAW
REGINA
MEDICINE HAT
LETHBRIDGE
ALBERTA
SASKATCHEWAN
CANADA
U.S.A.
A
A'
B
B'
C
C'
D
D'
E
E'
F
F'
G
G'
H
H'
O
O'
LOCATION MAP
Mi 30 0 30 MI.
km 60 30 0 60 km

Figure 7 — Southwest-northeast stratigraphic cross-section A-A' of Lower Colorado strata between the Mid-Continent Trillium Beauvallion No. 1 (Lsd 14-11-53-10W4) and Banff Aquit B1 Muskeg 10-8-65-22 (Lsd 10-8-65-22W3) wells.

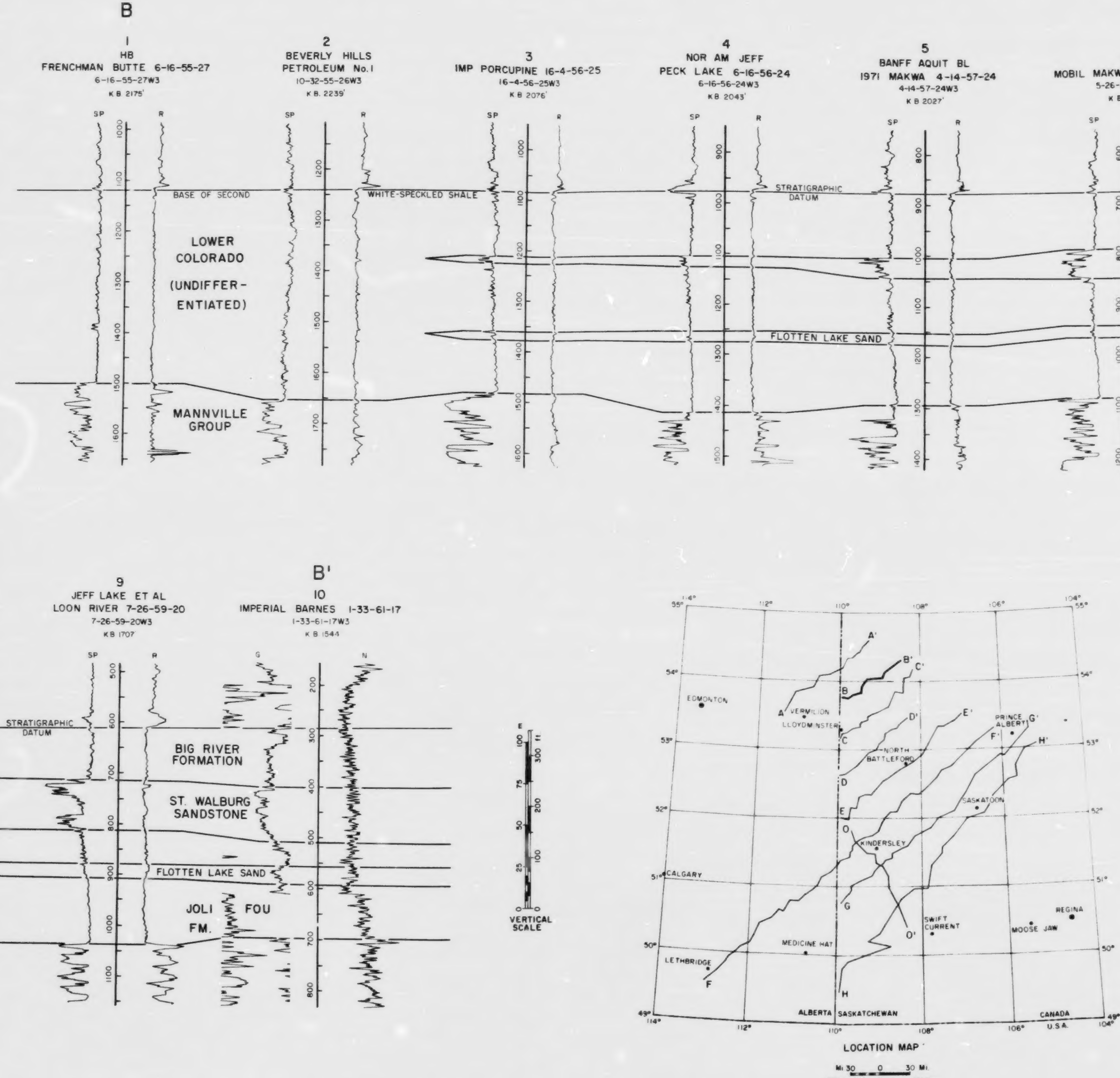
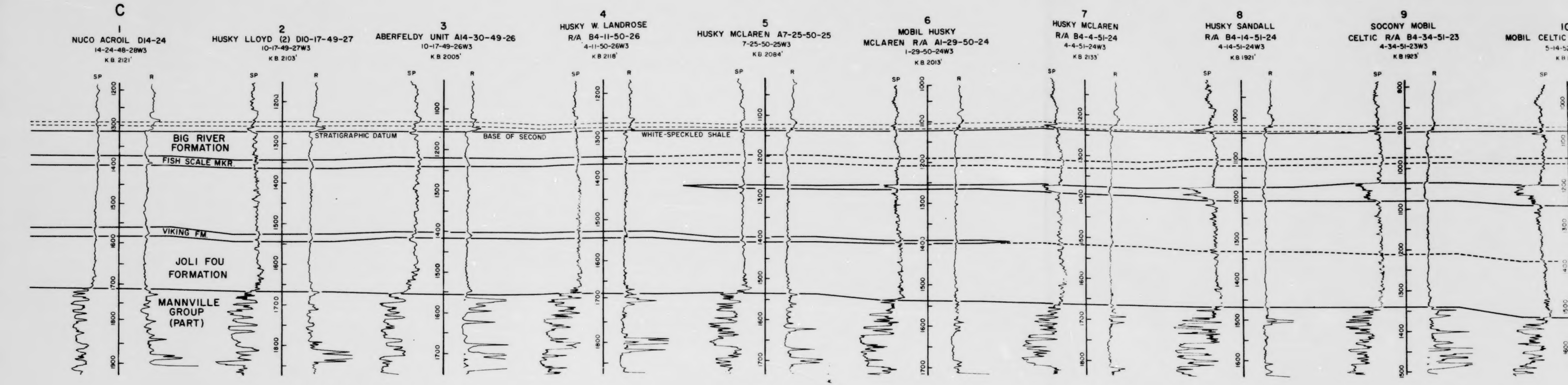
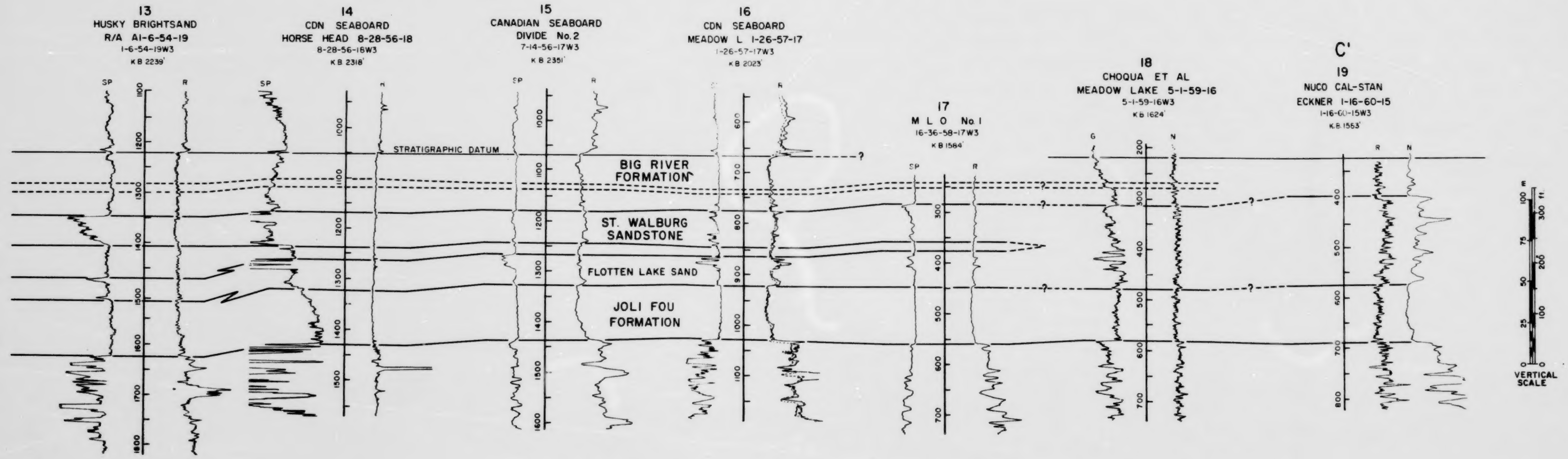
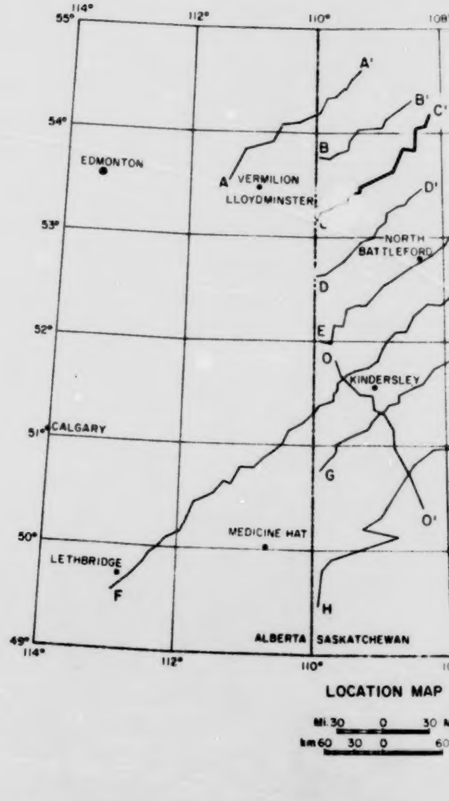
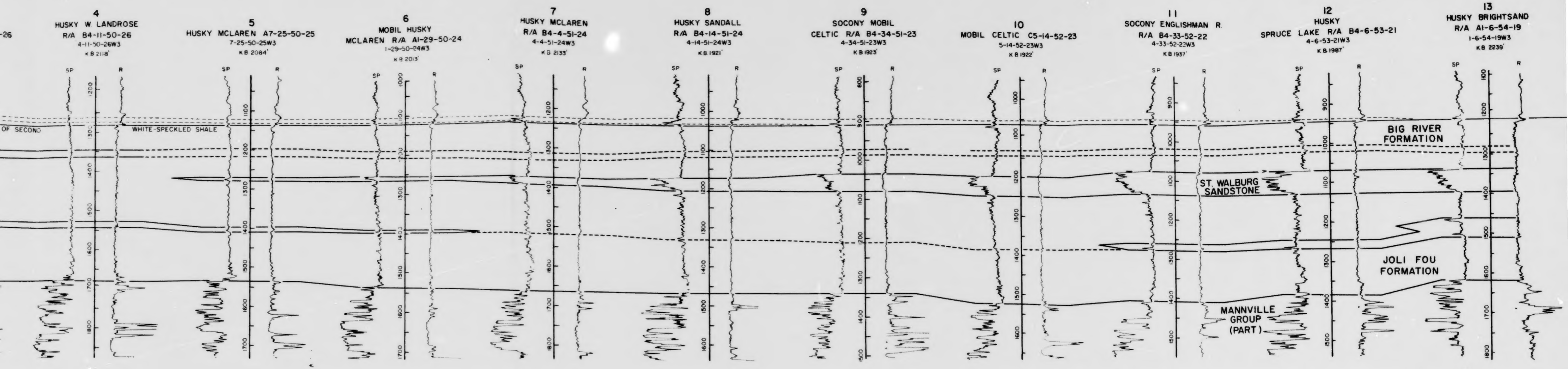

B
1
HB
FRENCHMAN BUTTE 6-16-55-27
6-16-55-27W3
K B 2175'
2
BEVERLY HILLS
PETROLEUM No. 1
10-32-55-26W3
K B 2239'
3
IMP PORCUPINE 16-4-56-25
16-4-56-25W3
K B 2076'
4
NOR AM JEFF
PECK LAKE 6-16-56-24
6-16-56-24W3
K B 2043'
5
BANFF AQUIT BL
1971 MAKWA 4-14-57-24
4-14-57-24W3
K B 2027'
6
MOBIL MAKWA 5-26-58-23
5-26-58-23W3
K B 1797'
7
TIDEWATER MEADOW LAKE
CROWN No. 4-34
4-34-58-21W3
K B 1844'
8
JEFF LAKE ET AL
N MAKWA 11-31-58-20
11-31-58-20W3
K B 1701'
9
JEFF LAKE ET AL
LOON RIVER 7-26-59-20
7-26-59-20W3
K B 1707'
SP
R
BASE OF SECOND
WHITE-SPECKLED SHALE
STRATIGRAPHIC DATUM
LOWER COLORADO
(UNDIFFERENTIATED)
ST. WALBURG SANDSTONE
FLOTTEN LAKE SAND
MANNVILLE GROUP
B'
10
IMPERIAL BARNES 1-33-61-17
1-33-61-17W3
K B 1544
G
N
BIG RIVER FORMATION
JOLI FOU FM.
VERTICAL SCALE
m
ft
LOCATION MAP
EDMONTON
VERMILION
LLOYDMINSTER
NORTH BATTLEFORD
PRINCE ALBERT
SASKATOON
KINDERSLEY
CALGARY
SWIFT CURRENT
REGINA
MOOSE JAW
MEDICINE HAT
LETHBRIDGE
ALBERTA
SASKATCHEWAN
CANADA
U.S.A.
A A' B B' C C' D D' E E' F F' G G' H H' O O'
Mi 30 0 30 Mi
km 60 30 0 60 km

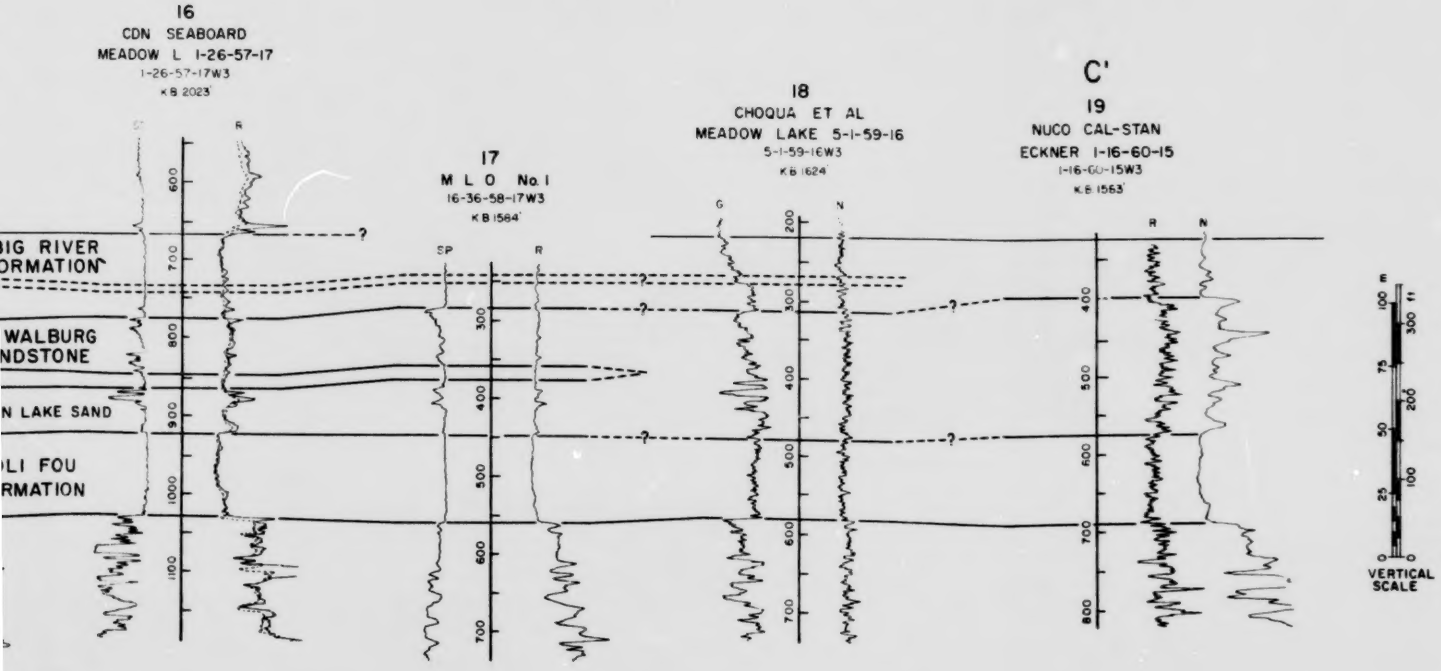
Figure 8 — Southwest-northeast stratigraphic cross-section B-B' of Lower Colorado strata between the HB Frenchman Butte 6-16-55-27 (Lsd 6-16-55-27W3) and Imperial Barnes 1-33-61-17 (Lsd 1-33-61-17W3) wells.


C
1 NUCO ACROIL D14-24 14-24-48-28W3 K.B. 2121'
2 HUSKY LLOYD (2) D10-17-49-27 10-17-49-27W3 K.B. 2103'
3 ABERFELDY UNIT A14-30-49-26 10-17-49-26W3 K.B. 2005'
4 HUSKY W. LANDROSE R/A B4-11-50-26 4-11-50-26W3 K.B. 2118'
5 HUSKY MCLAREN A7-25-50-25 7-25-50-25W3 K.B. 2084'
6 MOBIL HUSKY MCLAREN R/A A1-29-50-24 1-29-50-24W3 K.B. 2013'
7 HUSKY MCLAREN R/A B4-4-51-24 4-4-51-24W3 K.B. 2133'
8 HUSKY SANDALL R/A B4-14-51-24 4-14-51-24W3 K.B. 1921'
9 SOCONY MOBIL CELTIC R/A B4-34-51-23 4-34-51-23W3 K.B. 1923'
MOBIL CELTIC
SP
R
BIG RIVER FORMATION
STRATIGRAPHIC DATUM
BASE OF SECOND
WHITE-SPECKLED SHALE
FISH SCALE MKR.
VIKING FM.
JOLI FOU FORMATION
MANNVILLE GROUP (PART)


13 HUSKY BRIGHTSAND R/A A1-6-54-19 1-6-54-19W3 K.B. 2239'
14 CDN SEABOARD HORSE HEAD 8-28-56-18 8-28-56-18W3 K.B. 2318'
15 CANADIAN SEABOARD DIVIDE No. 2 7-14-56-17W3 K.B. 2351'
16 CDN SEABOARD MEADOW L 1-26-57-17 1-26-57-17W3 K.B. 2023'
17 M L O No. 1 16-36-58-17W3 K.B. 1584'
18 CHOQUA ET AL MEADOW LAKE 5-1-59-16 5-1-59-16W3 K.B. 1624'
C'
19 NUCO CAL-STAN ECKNER 1-16-60-15 1-16-60-15W3 K.B. 1563'
SP
R
G
N
STRATIGRAPHIC DATUM
BIG RIVER FORMATION
ST. WALBURG SANDSTONE
FLOTTEN LAKE SAND
JOLI FOU FORMATION
?
VERTICAL SCALE
m
ft
0
25
50
75
100
100
200
300


LOCATION MAP
EDMONTON
VERMILION
LLOYDMINSTER
NORTH BATTLEFORD
KINDERSLEY
CALGARY
MEDICINE HAT
LETHBRIDGE
ALBERTA
SASKATCHEWAN
A
A'
B
B'
C'
D
D'
E
O
O'
F
G
H
55°
54°
53°
52°
51°
50°
49°
114°
112°
110°
Mi 30 0 30
km 60 30 0 60


-26
4
HUSKY W. LANDROSE
R/A B4-11-50-26
4-11-50-26W3
KB 2118'
5
HUSKY MCLAREN A7-25-50-25
7-25-50-25W3
KB 2084'
6
MOBIL HUSKY
MCLAREN R/A A1-29-50-24
1-29-50-24W3
KB 2013'
7
HUSKY MCLAREN
R/A B4-4-51-24
4-4-51-24W3
KB 2133'
8
HUSKY SANDALL
R/A B4-14-51-24
4-14-51-24W3
KB 1921'
9
SOCONY MOBIL
CELTIC R/A B4-34-51-23
4-34-51-23W3
KB 1923'
10
MOBIL CELTIC C5-14-52-23
5-14-52-23W3
KB 1922'
11
SOCONY ENGLISHMAN R.
R/A B4-33-52-22
4-33-52-22W3
KB 1937'
12
HUSKY
SPRUCE LAKE R/A B4-6-53-21
4-6-53-21W3
KB 1987'
13
HUSKY BRIGHTSAND
R/A A1-6-54-19
1-6-54-19W3
KB 2239'
SP
R
OF SECOND
WHITE-SPECKLED SHALE
BIG RIVER FORMATION
ST. WALBURG SANDSTONE
JOLI FOU FORMATION
MANNVILLE GROUP (PART)


16
CDN SEABOARD
MEADOW L 1-26-57-17
1-26-57-17W3
KB 2023'
17
M L O No. 1
16-36-58-17W3
KB 1584'
18
CHOQUA ET AL
MEADOW LAKE 5-1-59-16
5-1-59-16W3
KB 1624'
C'
19
NUCO CAL-STAN
ECKNER 1-16-60-15
1-16-60-15W3
KB 1563'
SP
R
G
N
BIG RIVER FORMATION
WALBURG NDSTONE
N LAKE SAND
OLI FOU RMATION
?
m
ft
0
25
50
75
100
200
300
VERTICAL SCALE

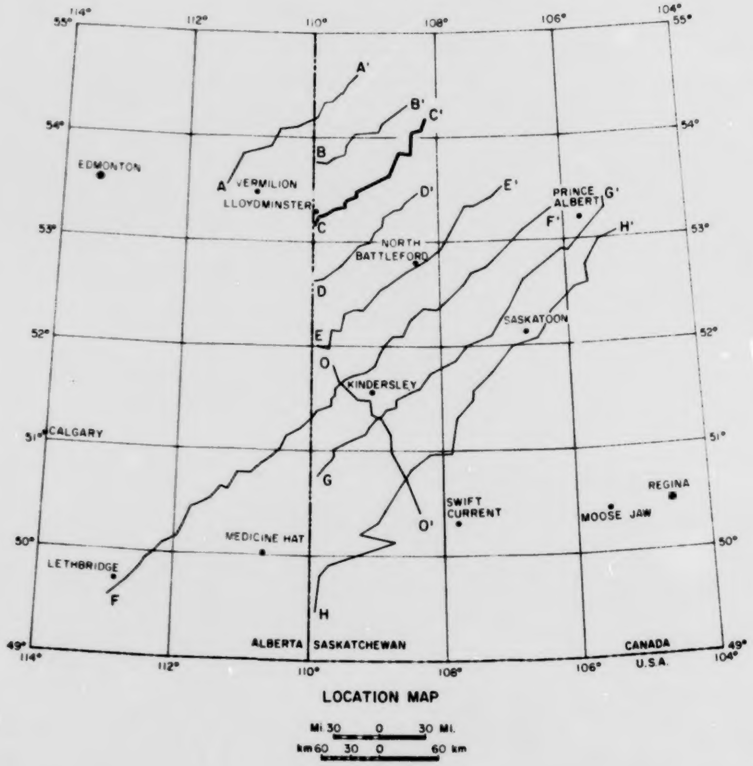

114°
112°
110°
108°
106°
104°
55°
54°
53°
52°
51°
50°
49°
EDMONTON
VERMILION
LLOYDMINSTER
NORTH BATTLEFORD
PRINCE ALBERT
SASKATOON
KINDERSLEY
CALGARY
SWIFT CURRENT
MOOSE JAW
REGINA
MEDICINE HAT
LETHBRIDGE
A
A'
B
B'
C
C'
D
D'
E
E'
F
F'
G
G'
H
H'
O
O'
ALBERTA
SASKATCHEWAN
CANADA
U.S.A.
LOCATION MAP
Mi 30 0 30 Mi.
km 60 30 0 60 km

Figure 9 — Southwest-northeast stratigraphic cross-section C-C' of Lower Colorado strata between the Nuco Acroil D-14-24 (Lsd 14-24-48-28W3) and Nuco Cal-Stan Eckner 1-16-60-15 (Lsd 1-16-60-15W3) wells.

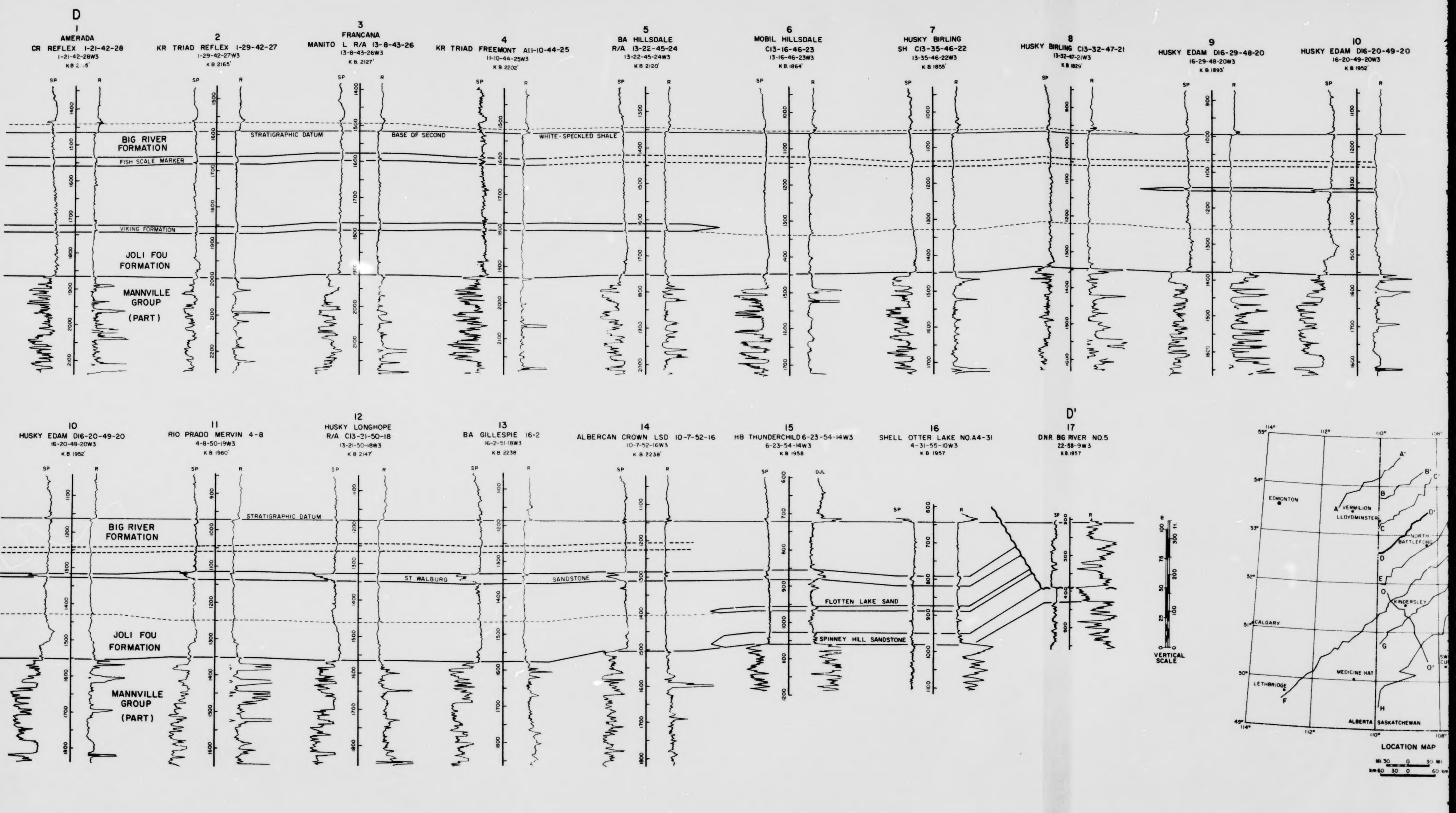

D
1
AMERADA
CR REFLEX 1-21-42-28
1-21-42-28W3
K.B. 2 15'
2
KR TRIAD REFLEX 1-29-42-27
1-29-42-27W3
K.B. 2165'
3
FRANCANA
MANITO L R/A 13-8-43-26
13-8-43-26W3
K.B. 2127'
4
KR TRIAD FREEMONT A11-10-44-25
11-10-44-25W3
K.B. 2202'
5
BA HILLSDALE
R/A 13-22-45-24
13-22-45-24W3
K.B. 2120'
6
MOBIL HILLSDALE
C13-16-46-23
13-16-46-23W3
K.B. 1864'
7
HUSKY BIRLING
SH C13-35-46-22
13-35-46-22W3
K.B. 1855'
8
HUSKY BIRLING C13-32-47-21
13-32-47-21W3
K.B. 1829'
9
HUSKY EDAM D16-29-48-20
16-29-48-20W3
K.B. 1893'
10
HUSKY EDAM D16-20-49-20
16-20-49-20W3
K.B. 1952'
SP
R
BIG RIVER FORMATION
STRATIGRAPHIC DATUM
BASE OF SECOND
WHITE-SPECKLED SHALE
FISH SCALE MARKER
VIKING FORMATION
JOLI FOU FORMATION
MANNVILLE GROUP (PART)
10
HUSKY EDAM D16-20-49-20
16-20-49-20W3
K.B. 1952'
11
RIO PRADO MERVIN 4-8
4-8-50-19W3
K.B. 1960'
12
HUSKY LONGHOPE
R/A C13-21-50-18
13-21-50-18W3
K.B. 2147'
13
BA GILLESPIE 16-2
16-2-51-18W3
K.B. 2238
14
ALBERCAN CROWN LSD 10-7-52-16
10-7-52-16W3
K.B. 2238'
15
HB THUNDERCHILD 6-23-54-14W3
6-23-54-14W3
K.B. 1958
16
SHELL OTTER LAKE NO.A4-31
4-31-55-10W3
K.B. 1957
D'
17
DNR BIG RIVER NO.5
22-58-9W3
K.B. 1957
DJL
ST WALBURG SANDSTONE
FLOTTEN LAKE SAND
SPINNEY HILL SANDSTONE
m
ft.
VERTICAL SCALE
LOCATION MAP
EDMONTON
VERMILION
LLOYDMINSTER
NORTH BATTLEFORD
KINDERSLEY
CALGARY
MEDICINE HAT
LETHBRIDGE
ALBERTA
SASKATCHEWAN
A
A'
B
B'
C
C'
D
D'
E
O
O'
G
F
H
114°
112°
110°
108°
55°
54°
53°
52°
51°
50°
49°
Mi 30 0 30 Mi
km 60 30 0 60 km

Figure 10 — Southwest-northeast stratigraphic cross-section D-D' of Lower Colorado str

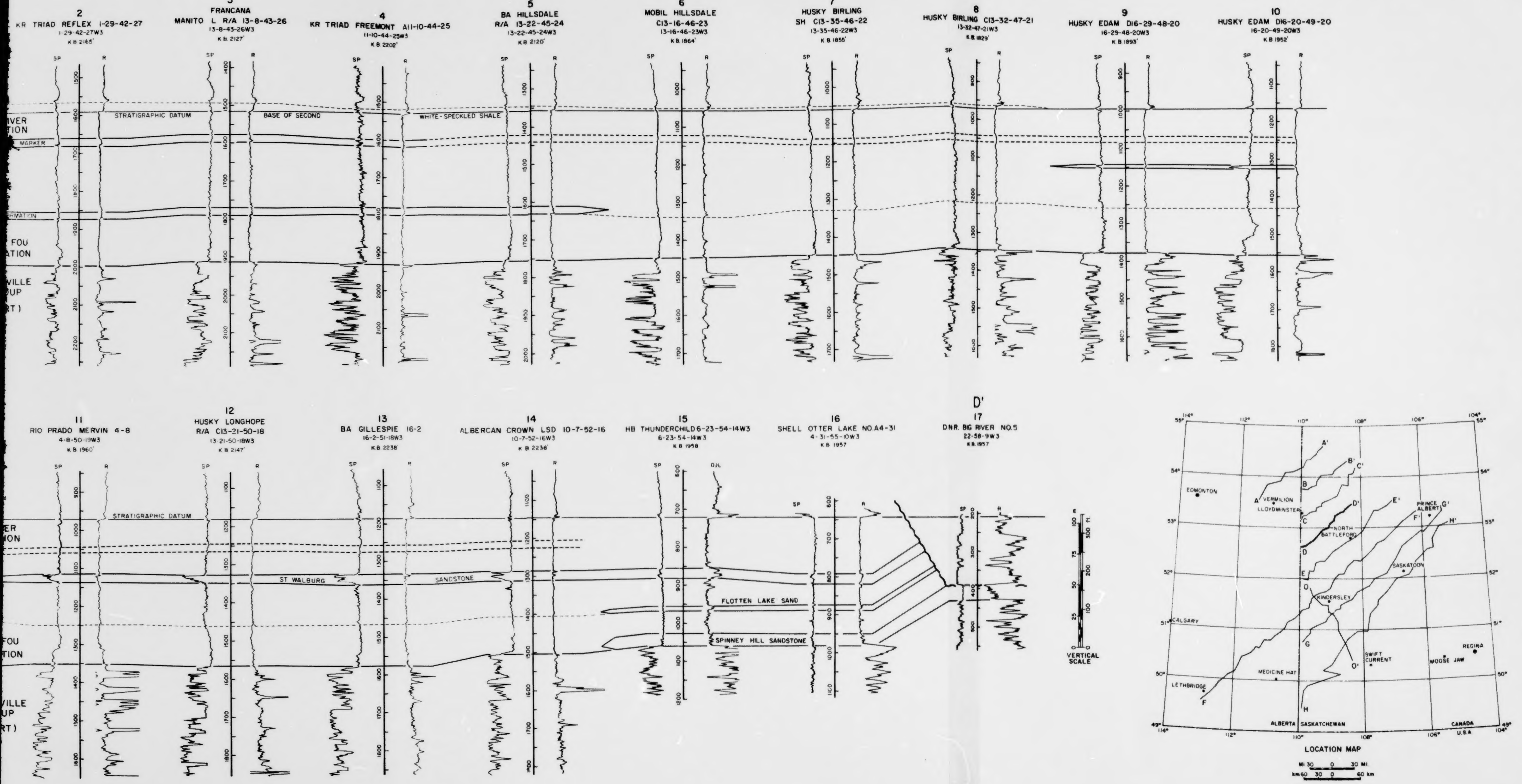
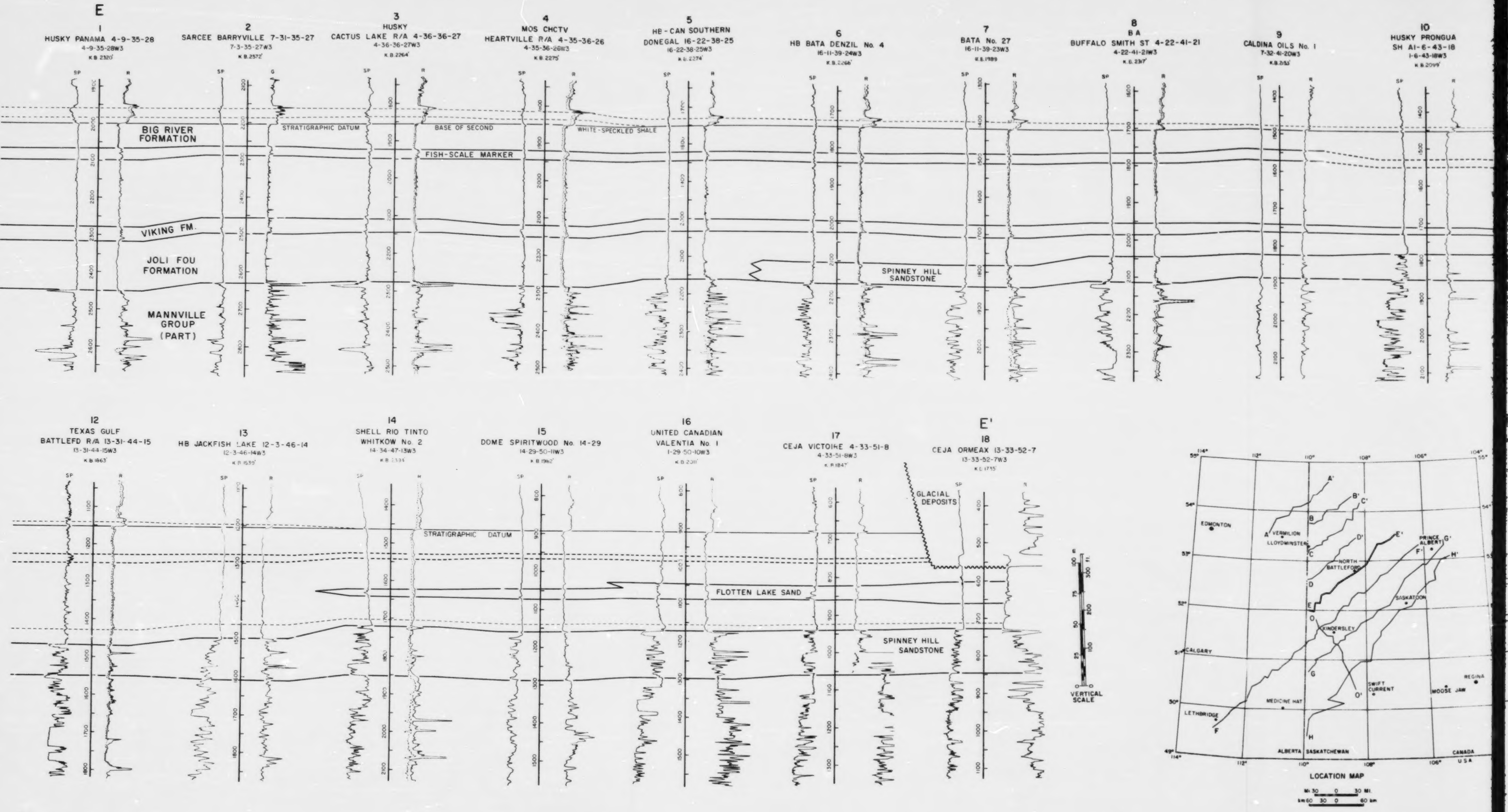

2
KR TRIAD REFLEX 1-29-42-27
1-29-42-27W3
K.B. 2165'
3
FRANCANA
MANITO L R/A 13-8-43-26
13-8-43-26W3
K.B. 2127'
4
KR TRIAD FREEMONT A11-10-44-25
11-10-44-25W3
K.B. 2202'
5
BA HILLSDALE
R/A 13-22-45-24
13-22-45-24W3
K.B. 2120'
6
MOBIL HILLSDALE
C13-16-46-23
13-16-46-23W3
K.B. 1864'
7
HUSKY BIRLING
SH C13-35-46-22
13-35-46-22W3
K.B. 1855'
8
HUSKY BIRLING C13-32-47-21
13-32-47-21W3
K.B. 1829'
9
HUSKY EDAM D16-29-48-20
16-29-48-20W3
K.B. 1893'
10
HUSKY EDAM D16-20-49-20
16-20-49-20W3
K.B. 1952'
SP
R
IVER
TION
MARKER
RMATION
FOU
ATION
VILLE
UP
RT)
STRATIGRAPHIC DATUM
BASE OF SECOND
WHITE-SPECKLED SHALE
D'
11
RIO PRADO MERVIN 4-8
4-8-50-19W3
K.B. 1960'
12
HUSKY LONGHOPE
R/A C13-21-50-18
13-21-50-18W3
K.B. 2147'
13
BA GILLESPIE 16-2
16-2-51-18W3
K.B. 2238'
14
ALBERCAN CROWN LSD 10-7-52-16
10-7-52-16W3
K.B. 2238'
15
HB THUNDERCHILD 6-23-54-14W3
6-23-54-14W3
K.B. 1958
16
SHELL OTTER LAKE NO. A4-31
4-31-55-10W3
K.B. 1957
17
DNR BIG RIVER NO. 5
22-58-9W3
K.B. 1957
DJL
ER
ON
STRATIGRAPHIC DATUM
ST WALBURG
SANDSTONE
FLOTTEN LAKE SAND
SPINNEY HILL SANDSTONE
FOU
TION
VILLE
UP
RT)
m
ft.
VERTICAL SCALE
LOCATION MAP
EDMONTON
VERMILION
LLOYDMINSTER
NORTH BATTLEFORD
PRINCE ALBERT
SASKATOON
KINDERSLEY
CALGARY
SWIFT CURRENT
MOOSE JAW
REGINA
MEDICINE HAT
LETHBRIDGE
ALBERTA
SASKATCHEWAN
CANADA
U.S.A.
A A' B B' C C' D D' E E' F F' G G' H H' O O'
Mi 30 0 30 Mi.
km 60 30 0 60 km

Figure 10 — Southwest-northeast stratigraphic cross-section D-D' of Lower Colorado strata between the Amerada CR Reflex 1-21-42-28 (Lsd 1-21-42-28W3) and DNR Big River No. 5 (Sec. 22-58-9W3) wells.


E
1
HUSKY PANAMA 4-9-35-28
4-9-35-28W3
K.B. 2320'
2
SARCEE BARRYVILLE 7-31-35-27
7-3-35-27W3
K.B. 2572'
3
HUSKY
CACTUS LAKE R/A 4-36-36-27
4-36-36-27W3
K.B. 2264'
4
MOS CHCTV
HEARTVILLE R/A 4-35-36-26
4-35-36-26W3
K.B. 2275'
5
HB - CAN SOUTHERN
DONEGAL 16-22-38-25
16-22-38-25W3
K.B. 2274'
6
HB BATA DENZIL No. 4
16-11-39-24W3
K.B. 2266'
7
BATA No. 27
16-11-39-23W3
K.B. 1989
8
B A
BUFFALO SMITH ST 4-22-41-21
4-22-41-21W3
K.B. 2317'
9
CALDINA OILS No. 1
7-32-41-20W3
K.B. 2153'
10
HUSKY PRONGUA
SH A1-6-43-18
1-6-43-18W3
K.B. 2099'
SP
R
G
BIG RIVER FORMATION
STRATIGRAPHIC DATUM
BASE OF SECOND
WHITE-SPECKLED SHALE
FISH-SCALE MARKER
VIKING FM.
JOLI FOU FORMATION
SPINNEY HILL SANDSTONE
MANNVILLE GROUP (PART)
12
TEXAS GULF
BATTLEFD R/A 13-31-44-15
13-31-44-15W3
K.B. 1663'
13
HB JACKFISH LAKE 12-3-46-14
12-3-46-14W3
K.B. 1639'
14
SHELL RIO TINTO
WHITKOW No. 2
14-34-47-13W3
K.B. 2334'
15
DOME SPIRITWOOD No. 14-29
14-29-50-11W3
K.B. 1962'
16
UNITED CANADIAN
VALENTIA No. 1
1-29-50-10W3
K.B. 2011'
17
CEJA VICTOIRE 4-33-51-8
4-33-51-8W3
K.B. 1847'
E'
18
CEJA ORMEAX 13-33-52-7
13-33-52-7W3
K.B. 1735'
GLACIAL DEPOSITS
STRATIGRAPHIC DATUM
FLOTTEN LAKE SAND
SPINNEY HILL SANDSTONE
m
ft.
100
75
50
25
0
300
200
100
0
VERTICAL SCALE
114°
112°
110°
108°
106°
104°
55°
54°
53°
52°
51°
50°
49°
A
A'
B
B'
C
C'
D
D'
E
E'
F
F'
G
G'
H
H'
O
O'
EDMONTON
VERMILION
LLOYDMINSTER
NORTH BATTLEFORD
PRINCE ALBERT
SASKATOON
KINDERSLEY
CALGARY
SWIFT CURRENT
MOOSE JAW
REGINA
MEDICINE HAT
LETHBRIDGE
ALBERTA
SASKATCHEWAN
CANADA
U.S.A.
LOCATION MAP
Mi 30 0 30 Mi
km 60 30 0 60 km

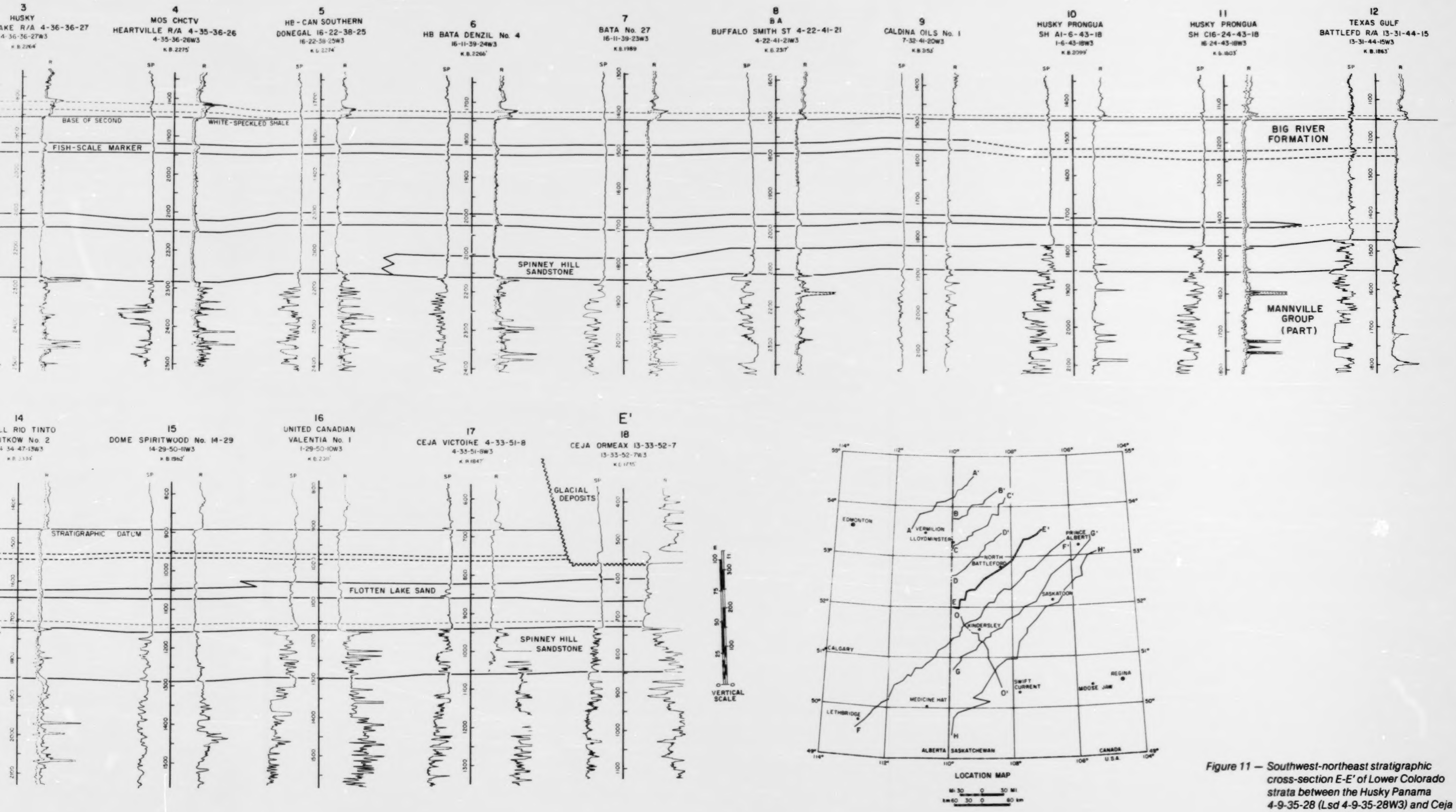
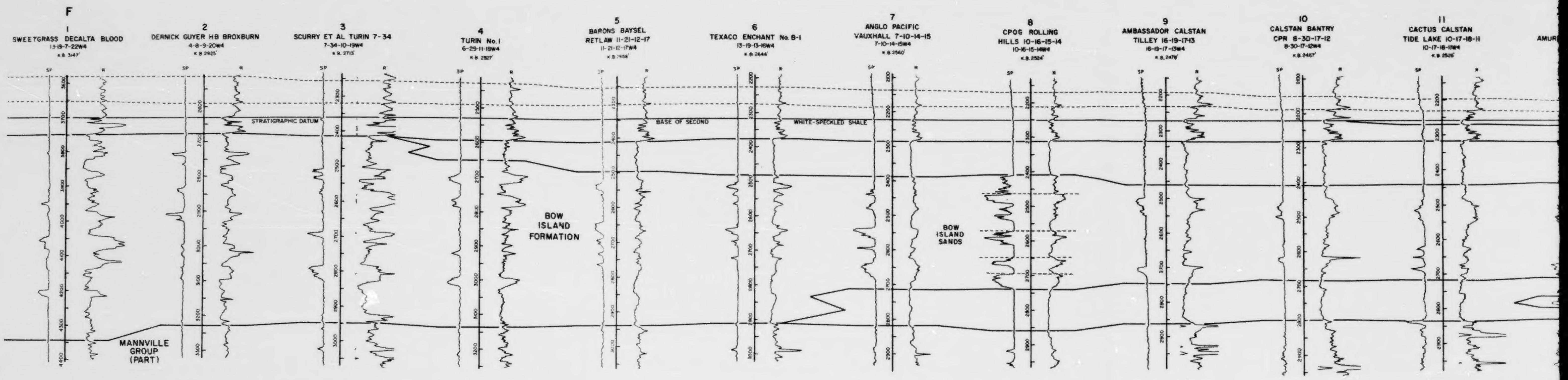
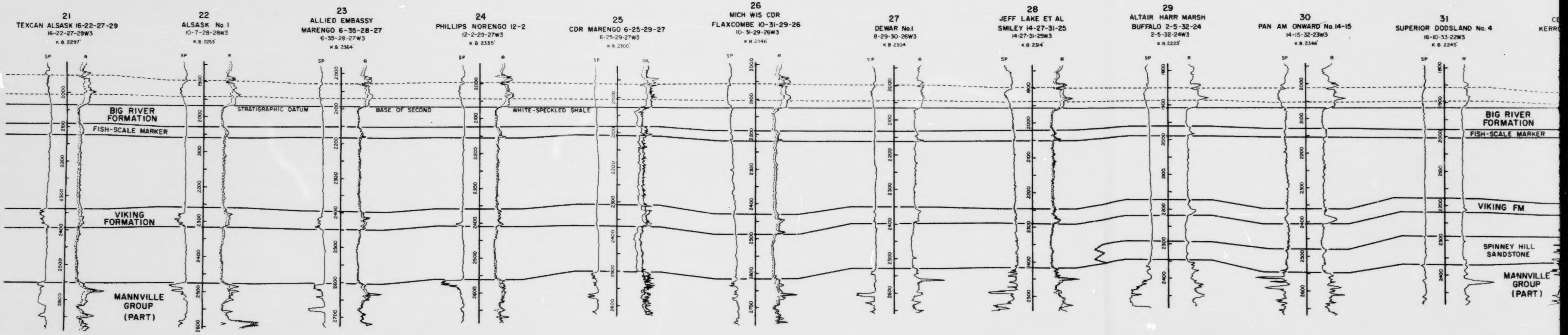
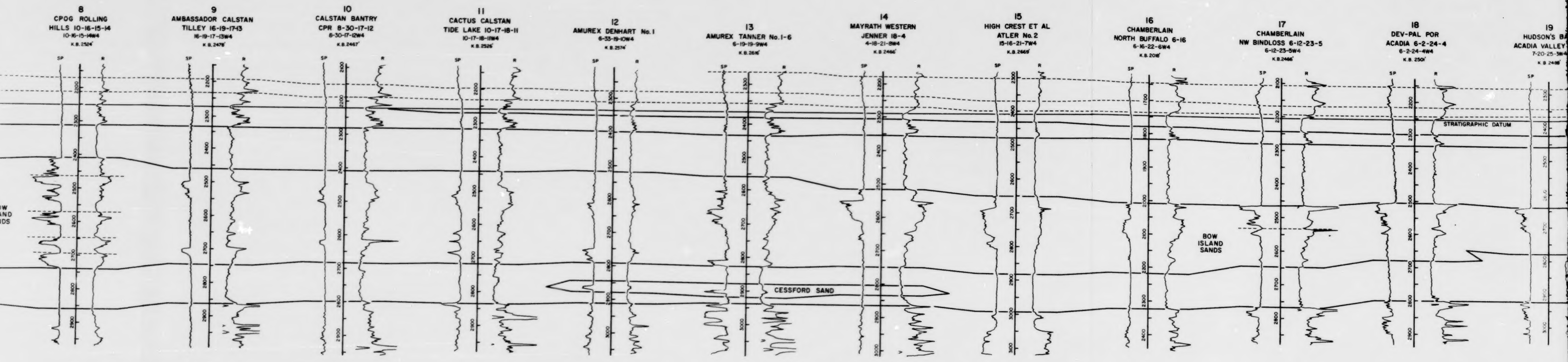
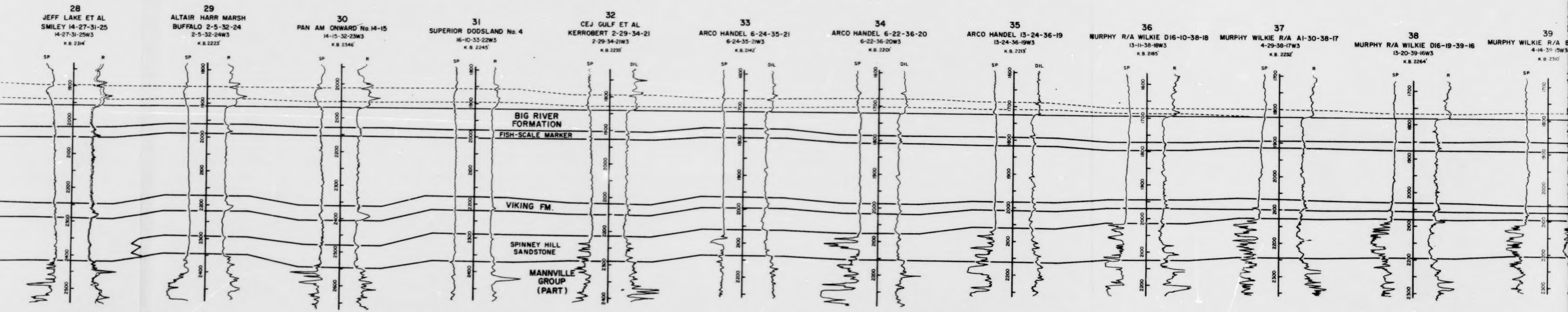

3
HUSKY
AKE R/A 4-36-36-27
4-36-36-27W3
K.B.2264'
4
MOS CHCTV
HEARTVILLE R/A 4-35-36-26
4-35-36-26W3
K.B.2275'
5
HB - CAN SOUTHERN
DONEGAL 16-22-38-25
16-22-38-25W3
K.B.2274'
6
HB BATA DENZIL No. 4
16-11-39-24W3
K.B.2266'
7
BATA No. 27
16-11-39-23W3
K.B.1989
8
B A
BUFFALO SMITH ST 4-22-41-21
4-22-41-21W3
K.B.2317'
9
CALDINA OILS No. 1
7-32-41-20W3
K.B.2153'
10
HUSKY PRONGUA
SH A1-6-43-18
1-6-43-18W3
K.B.2099'
11
HUSKY PRONGUA
SH C16-24-43-18
16-24-43-18W3
K.B.1803'
12
TEXAS GULF
BATTLEFD R/A 13-31-44-15
13-31-44-15W3
K.B.1863'
SP
R
BASE OF SECOND
WHITE-SPECKLED SHALE
FISH-SCALE MARKER
BIG RIVER FORMATION
SPINNEY HILL SANDSTONE
MANNVILLE GROUP (PART)
14
LL RIO TINTO
ITKOW No. 2
4-34-47-13W3
K.B.2334'
15
DOME SPIRITWOOD No. 14-29
14-29-50-11W3
K.B.1962'
16
UNITED CANADIAN
VALENTIA No. 1
1-29-50-10W3
K.B.2311'
17
CEJA VICTOIRE 4-33-51-8
4-33-51-8W3
K.B.1847'
E'
18
CEJA ORMEAX 13-33-52-7
13-33-52-7W3
K.B.1735'
GLACIAL DEPOSITS
STRATIGRAPHIC DATUM
FLOTTEN LAKE SAND
SPINNEY HILL SANDSTONE
VERTICAL SCALE
m
ft
114°
112°
110°
108°
106°
104°
55°
54°
53°
52°
51°
50°
49°
EDMONTON
VERMILION
LLOYDMINSTER
NORTH BATTLEFORD
PRINCE ALBERT
SASKATOON
KINDERSLEY
CALGARY
MEDICINE HAT
LETHBRIDGE
SWIFT CURRENT
MOOSE JAW
REGINA
A
A'
B
B'
C
C'
D
D'
E
E'
F
F'
G
G'
H
H'
O
O'
ALBERTA
SASKATCHEWAN
CANADA
U.S.A.
LOCATION MAP
Mi 30 0 30 Mi
km 60 30 0 60 km

Figure 11 — Southwest-northeast stratigraphic cross-section E-E' of Lower Colorado strata between the Husky Panama 4-9-35-28 (Lsd 4-9-35-28W3) and Ceja Ormeaux 13-33-52-7 (Lsd 13-33-52-7W3)


F
1
SWEETGRASS DECALTA BLOOD
13-19-7-22W4
K.B. 3147'
2
DERNICK GUYER HB BROXBURN
4-8-9-20W4
K.B. 2925'
3
SCURRY ET AL TURIN 7-34
7-34-10-19W4
K.B. 2713'
4
TURIN No. 1
6-29-11-18W4
K.B. 2827'
5
BARONS BAYSEL
RETLAW 11-21-12-17
11-21-12-17W4
K.B. 2656'
6
TEXACO ENCHANT No. B-1
13-19-13-16W4
K.B. 2644'
7
ANGLO PACIFIC
VAUXHALL 7-10-14-15
7-10-14-15W4
K.B. 2560'
8
CPOG ROLLING
HILLS 10-16-15-14
10-16-15-14W4
K.B. 2524'
9
AMBASSADOR CALSTAN
TILLEY 16-19-17-13
16-19-17-13W4
K.B. 2478'
10
CALSTAN BANTRY
CPR 8-30-17-12
8-30-17-12W4
K.B. 2467'
11
CACTUS CALSTAN
TIDE LAKE 10-17-18-11
10-17-18-11W4
K.B. 2526'
AMUR
SP
R
STRATIGRAPHIC DATUM
BASE OF SECOND
WHITE-SPECKLED SHALE
BOW ISLAND FORMATION
BOW ISLAND SANDS
MANNVILLE GROUP (PART)


21
TEXCAN ALSASK 16-22-27-29
16-22-27-29W3
K.B. 2297'
22
ALSASK No. 1
10-7-28-28W3
K.B. 2253'
23
ALLIED EMBASSY
MARENGO 6-35-28-27
6-35-28-27W3
K.B. 2364'
24
PHILLIPS NORENGO 12-2
12-2-29-27W3
K.B. 2335'
25
CDR MARENGO 6-25-29-27
6-25-29-27W3
K.B. 2300'
26
MICH WIS CDR
FLAXCOMBE 10-31-29-26
10-31-29-26W3
K.B. 2346'
27
DEWAR No. 1
8-29-30-26W3
K.B. 2304
28
JEFF LAKE ET AL
SMILEY 14-27-31-25
14-27-31-25W3
K.B. 2314'
29
ALTAIR HARR MARSH
BUFFALO 2-5-32-24
2-5-32-24W3
K.B. 2223'
30
PAN AM ONWARD No. 14-15
14-15-32-23W3
K.B. 2346'
31
SUPERIOR DODSLAND No. 4
16-10-33-22W3
K.B. 2245'
CE
KERR
SP
R
DIL
STRATIGRAPHIC DATUM
BASE OF SECOND
WHITE-SPECKLED SHALE
BIG RIVER FORMATION
FISH-SCALE MARKER
VIKING FORMATION
VIKING FM.
SPINNEY HILL SANDSTONE
MANNVILLE GROUP (PART)


8
CPOG ROLLING
HILLS 10-16-15-14
10-16-15-14W4
K.B. 2524'
9
AMBASSADOR CALSTAN
TILLEY 16-19-17-13
16-19-17-13W4
K.B. 2478'
10
CALSTAN BANTRY
CPR 8-30-17-12
8-30-17-12W4
K.B. 2467'
11
CACTUS CALSTAN
TIDE LAKE 10-17-18-11
10-17-18-11W4
K.B. 2526'
12
AMUREX DENHART No. 1
6-33-19-10W4
K.B. 2574'
13
AMUREX TANNER No. 1-6
6-19-19-9W4
K.B. 2616'
14
MAYRATH WESTERN
JENNER 18-4
4-18-21-8W4
K.B. 2466'
15
HIGH CREST ET AL
ATLER No. 2
15-16-21-7W4
K.B. 2669'
16
CHAMBERLAIN
NORTH BUFFALO 6-16
6-16-22-6W4
K.B. 2018'
17
CHAMBERLAIN
NW BINDLOSS 6-12-23-5
6-12-23-5W4
K.B. 2466'
18
DEV-PAL POR
ACADIA 6-2-24-4
6-2-24-4W4
K.B. 2501'
19
HUDSON'S B
ACADIA VALLEY
7-20-25-3W4
K.B. 2488'
SP
R
STRATIGRAPHIC DATUM
W
AND
DS
BOW
ISLAND
SANDS
CESSFORD SAND


28
JEFF LAKE ET AL
SMILEY 14-27-31-25
14-27-31-25W3
K.B. 2314'
29
ALTAIR HARR MARSH
BUFFALO 2-5-32-24
2-5-32-24W3
K.B. 2223'
30
PAN AM ONWARD No. 14-15
14-15-32-23W3
K.B. 2346'
31
SUPERIOR DODSLAND No. 4
16-10-33-22W3
K.B. 2245'
32
CEJ GULF ET AL
KERROBERT 2-29-34-21
2-29-34-21W3
K.B. 2235'
33
ARCO HANDEL 6-24-35-21
6-24-35-21W3
K.B. 2142'
34
ARCO HANDEL 6-22-36-20
6-22-36-20W3
K.B. 2201'
35
ARCO HANDEL 13-24-36-19
13-24-36-19W3
K.B. 2213'
36
MURPHY R/A WILKIE D16-10-38-18
13-11-38-18W3
K.B. 2185'
37
MURPHY WILKIE R/A A1-30-38-17
4-29-38-17W3
K.B. 2232'
38
MURPHY R/A WILKIE D16-19-39-16
13-20-39-16W3
K.B. 2264'
39
MURPHY WILKIE R/A
4-14-39-15W3
K.B. 2310'
SP
R
DIL
BIG RIVER
FORMATION
FISH-SCALE MARKER
VIKING FM.
SPINNEY HILL
SANDSTONE
MANNVILLE
GROUP
(PART)

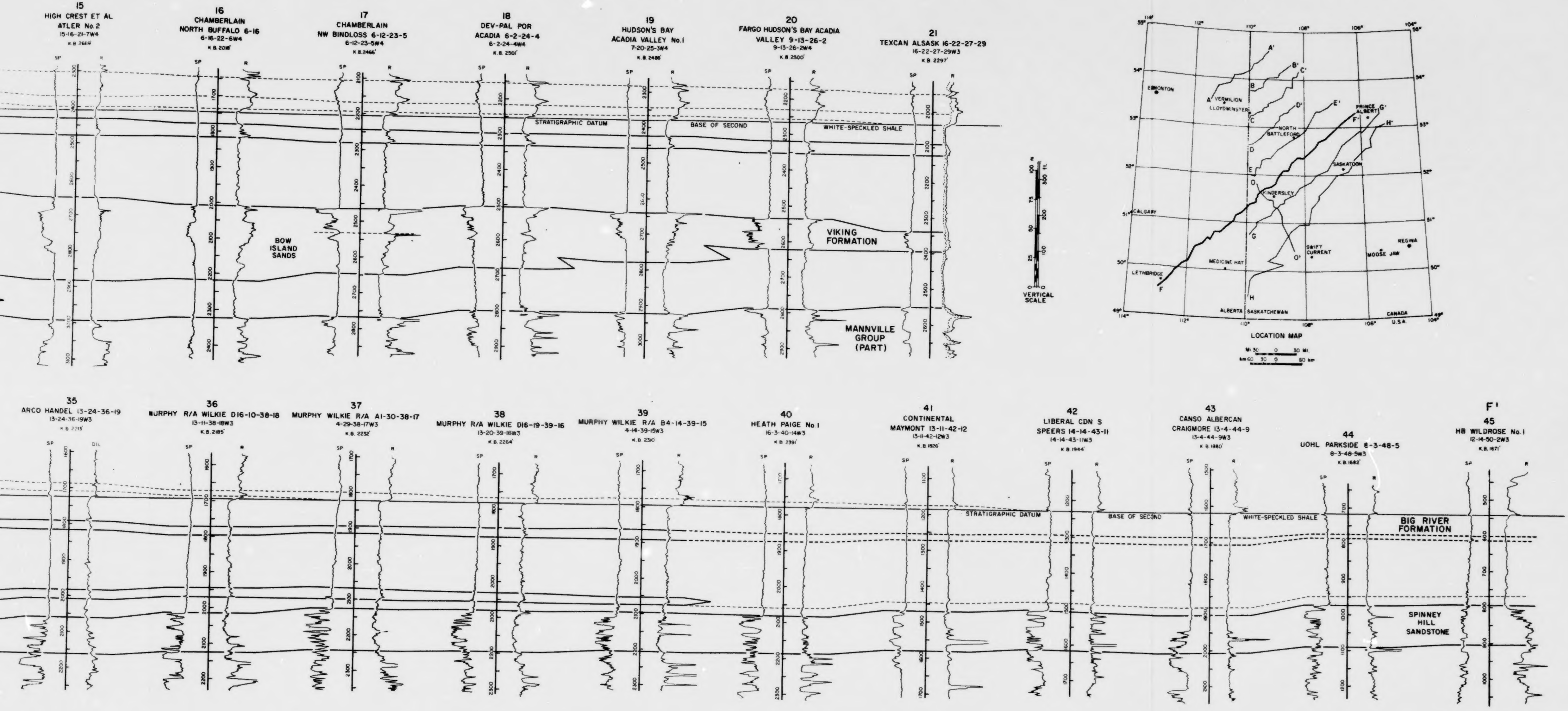
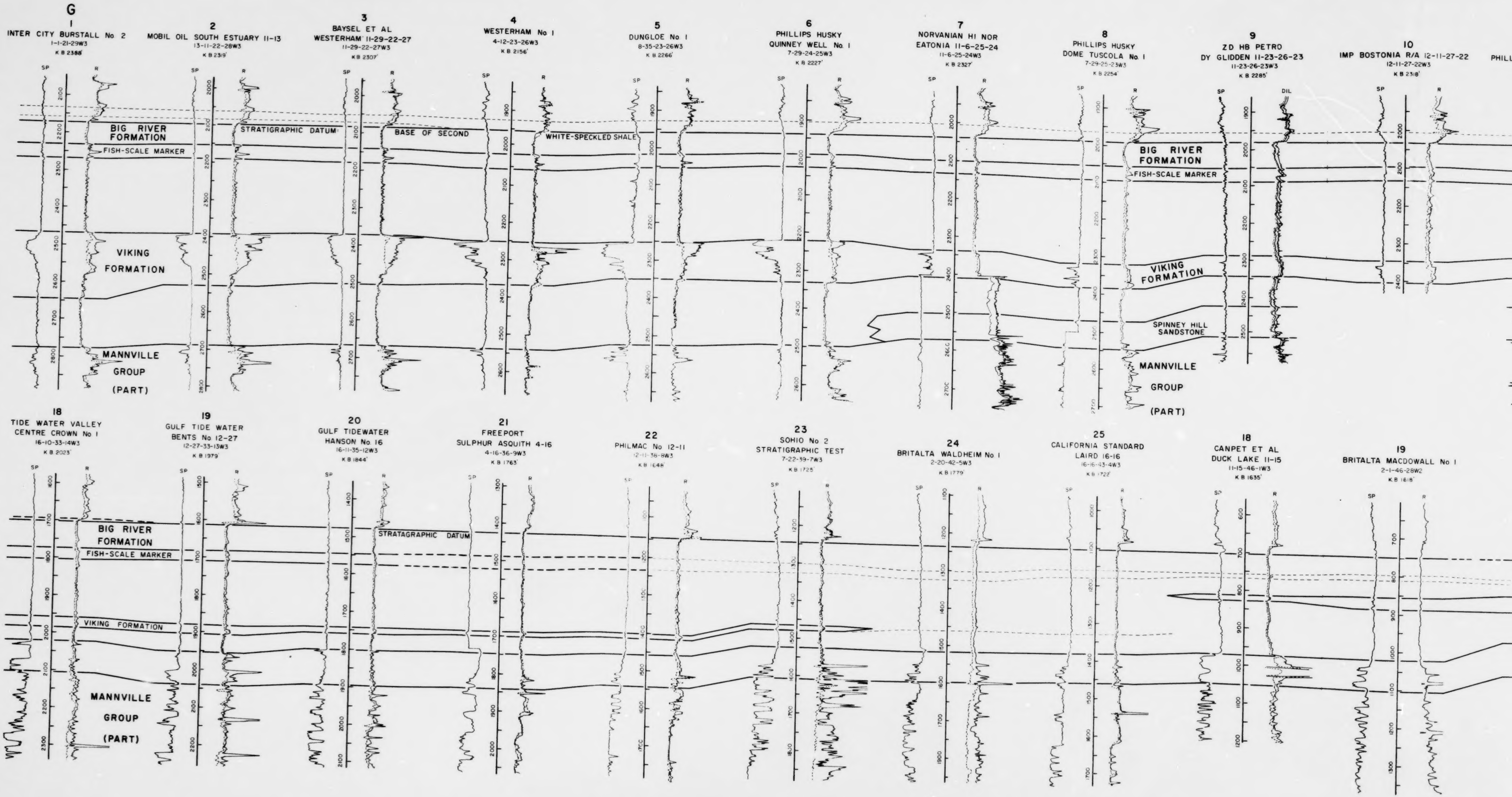

15
HIGH CREST ET AL
ATLER No.2
15-16-21-7W4
K.B. 2669'
16
CHAMBERLAIN
NORTH BUFFALO 6-16
6-16-22-6W4
K.B. 2018'
17
CHAMBERLAIN
NW BINDLOSS 6-12-23-5
6-12-23-5W4
K.B. 2466'
18
DEV-PAL POR
ACADIA 6-2-24-4
6-2-24-4W4
K.B. 2501'
19
HUDSON'S BAY
ACADIA VALLEY No.1
7-20-25-3W4
K.B. 2488'
20
FARGO HUDSON'S BAY ACADIA
VALLEY 9-13-26-2
9-13-26-2W4
K.B. 2500'
21
TEXCAN ALSASK 16-22-27-29
16-22-27-29W3
K.B. 2297'
SP
R
STRATIGRAPHIC DATUM
BASE OF SECOND
WHITE-SPECKLED SHALE
BOW ISLAND SANDS
VIKING FORMATION
MANNVILLE GROUP (PART)
0
25
50
75
100 m
0
100
200
300 ft.
VERTICAL SCALE
114°
112°
110°
108°
106°
104°
55°
54°
53°
52°
51°
50°
49°
A
A'
B
B'
C
C'
D
D'
E
E'
F
F'
G
G'
H
H'
O
O'
EDMONTON
VERMILION
LLOYDMINSTER
NORTH BATTLEFORD
PRINCE ALBERT
SASKATOON
KINDERSLEY
CALGARY
SWIFT CURRENT
REGINA
MOOSE JAW
MEDICINE HAT
LETHBRIDGE
ALBERTA
SASKATCHEWAN
CANADA
U.S.A.
LOCATION MAP
Mi 30 0 30 Mi.
km 60 30 0 60 km
35
ARCO HANDEL 13-24-36-19
13-24-36-19W3
K.B. 2213'
SP
DIL
36
MURPHY R/A WILKIE D16-10-38-18
13-11-38-18W3
K.B. 2185'
37
MURPHY WILKIE R/A A1-30-38-17
4-29-38-17W3
K.B. 2232'
38
MURPHY R/A WILKIE D16-19-39-16
13-20-39-16W3
K.B. 2264'
39
MURPHY WILKIE R/A B4-14-39-15
4-14-39-15W3
K.B. 2310
40
HEATH PAIGE No.1
16-3-40-14W3
K.B. 2391'
41
CONTINENTAL
MAYMONT 13-11-42-12
13-11-42-12W3
K.B. 1826'
42
LIBERAL CDN S
SPEERS 14-14-43-11
14-14-43-11W3
K.B. 1944'
43
CANSO ALBERCAN
CRAIGMORE 13-4-44-9
13-4-44-9W3
K.B. 1980'
44
UOHL PARKSIDE 8-3-48-5
8-3-48-5W3
K.B. 1682'
F'
45
HB WILDROSE No.1
12-14-50-2W3
K.B. 1671'
STRATIGRAPHIC DATUM
BASE OF SECOND
WHITE-SPECKLED SHALE
BIG RIVER FORMATION
SPINNEY HILL SANDSTONE

Figure 12 — Southwest-northeast stratigraphic cross-section F-F′ of Lower Colorado strata between the Sweetgrass Decalta Blood 13-19-7-22 (Lsd 13-19-7-22W4) and H. B. Wildrose No. 1 (Lsd 12-14-50-2W3) wells.


G
1
INTER CITY BURSTALL No. 2
1-1-21-29W3
K B 2388'
2
MOBIL OIL SOUTH ESTUARY 11-13
13-11-22-28W3
K B 2319'
3
BAYSEL ET AL
WESTERHAM 11-29-22-27
11-29-22-27W3
K B 2307'
4
WESTERHAM No. 1
4-12-23-26W3
K B 2156'
5
DUNGLOE No. 1
8-35-23-26W3
K B 2266'
6
PHILLIPS HUSKY
QUINNEY WELL No. 1
7-29-24-25W3
K B 2227'
7
NORVANIAN HI NOR
EATONIA 11-6-25-24
11-6-25-24W3
K B 2327'
8
PHILLIPS HUSKY
DOME TUSCOLA No. 1
7-29-25-23W3
K B 2254'
9
ZD HB PETRO
DY GLIDDEN 11-23-26-23
11-23-26-23W3
K B 2285'
10
IMP BOSTONIA R/A 12-11-27-22
12-11-27-22W3
K B 2318'
SP
R
DIL
BIG RIVER FORMATION
FISH-SCALE MARKER
STRATIGRAPHIC DATUM
BASE OF SECOND
WHITE-SPECKLED SHALE
VIKING FORMATION
SPINNEY HILL SANDSTONE
MANNVILLE GROUP (PART)
18
TIDE WATER VALLEY
CENTRE CROWN No. 1
16-10-33-14W3
K B 2023'
19
GULF TIDE WATER
BENTS No. 12-27
12-27-33-13W3
K B 1979'
20
GULF TIDEWATER
HANSON No. 16
16-11-35-12W3
K B 1844'
21
FREEPORT
SULPHUR ASQUITH 4-16
4-16-36-9W3
K B 1763'
22
PHILMAC No. 12-11
12-11-38-8W3
K B 1648'
23
SOHIO No. 2
STRATIGRAPHIC TEST
7-22-39-7W3
K B 1725'
24
BRITALTA WALDHEIM No. 1
2-20-42-5W3
K B 1779'
25
CALIFORNIA STANDARD
LAIRD 16-16
16-16-43-4W3
K B 1722'
18
CANPET ET AL
DUCK LAKE 11-15
11-15-46-1W3
K B 1635'
19
BRITALTA MACDOWALL No. 1
2-1-46-28W2
K B 1618'
BIG RIVER FORMATION
FISH-SCALE MARKER
STRATAGRAPHIC DATUM
VIKING FORMATION
MANNVILLE GROUP (PART)

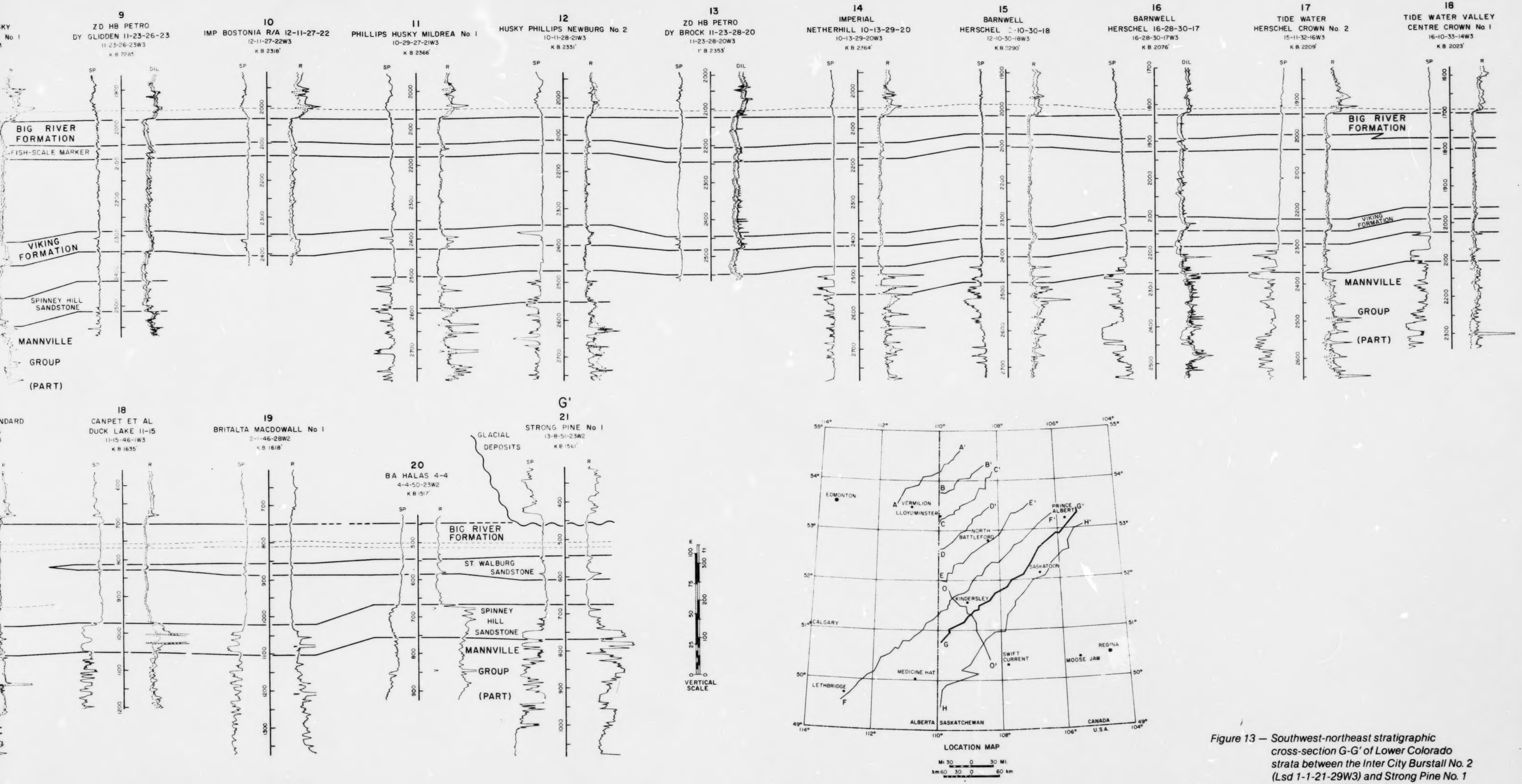
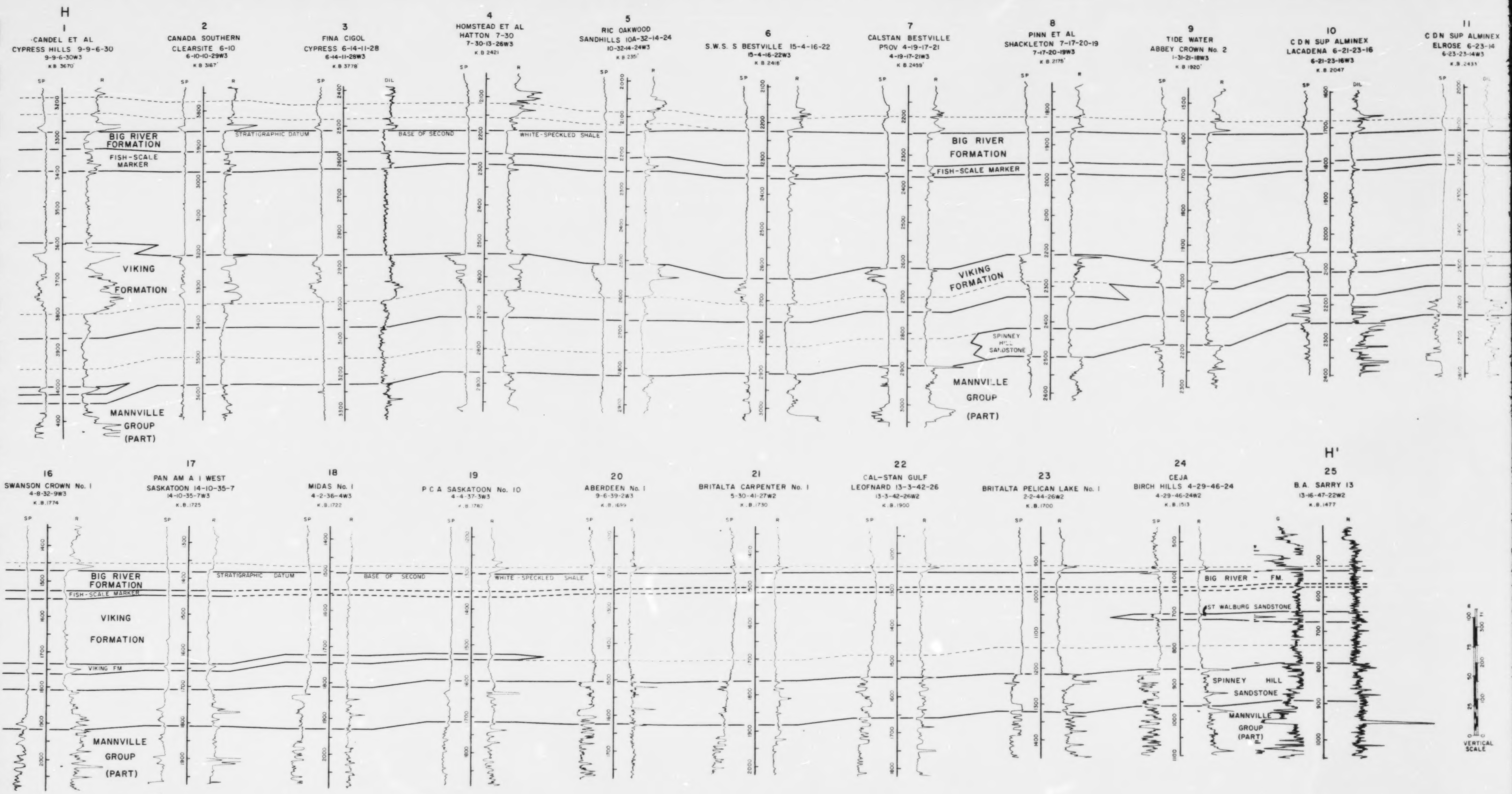

9
ZD HB PETRO
DY GLIDDEN 11-23-26-23
11-23-26-23W3
K B 2285'
10
IMP BOSTONIA R/A 12-11-27-22
12-11-27-22W3
K B 2318'
11
PHILLIPS HUSKY MILDREA No I
10-29-27-21W3
K B 2366'
12
HUSKY PHILLIPS NEWBURG No 2
10-11-28-21W3
K B 2331'
13
ZD HB PETRO
DY BROCK 11-23-28-20
11-23-28-20W3
K B 2353'
14
IMPERIAL
NETHERHILL 10-13-29-20
10-13-29-20W3
K B 2364'
15
BARNWELL
HERSCHEL 2-10-30-18
12-10-30-18W3
K B 2290'
16
BARNWELL
HERSCHEL 16-28-30-17
16-28-30-17W3
K B 2076'
17
TIDE WATER
HERSCHEL CROWN No. 2
15-11-32-16W3
K B 2209'
18
TIDE WATER VALLEY
CENTRE CROWN No I
16-10-33-14W3
K B 2023'
SP
R
DIL
BIG RIVER FORMATION
FISH-SCALE MARKER
VIKING FORMATION
SPINNEY HILL SANDSTONE
MANNVILLE GROUP (PART)
18
CANPET ET AL
DUCK LAKE 11-15
11-15-46-1W3
K B 1635'
19
BRITALTA MACDOWALL No I
2-1-46-28W2
K B 1618'
20
BA HALAS 4-4
4-4-50-23W2
K B 1517'
G'
21
STRONG PINE No I
13-8-51-23W2
K B 1561'
GLACIAL DEPOSITS
BIG RIVER FORMATION
ST. WALBURG SANDSTONE
SPINNEY HILL SANDSTONE
MANNVILLE GROUP (PART)
m 0 25 50 75 100
ft 0 100 200 300
VERTICAL SCALE
EDMONTON
VERMILION
LLOYDMINSTER
NORTH BATTLEFORD
PRINCE ALBERT
SASKATOON
KINDERSLEY
CALGARY
SWIFT CURRENT
MOOSE JAW
REGINA
MEDICINE HAT
LETHBRIDGE
ALBERTA
SASKATCHEWAN
CANADA
U.S.A.
A A' B B' C C' D D' E E' F F' G G' H H' O O'
LOCATION MAP
Mi 30 0 30 Mi
km 60 30 0 60 km

Figure 13 — Southwest-northeast stratigraphic cross-section G-G' of Lower Colorado strata between the Inter City Burstall No. 2 (Lsd 1-1-21-29W3) and Strong Pine No. 1 (Lsd 13-8-51-23W2) wells.


H
1
·CANDEL ET AL
CYPRESS HILLS 9-9-6-30
9-9-6-30W3
K.B 3670'
2
CANADA SOUTHERN
CLEARSITE 6-10
6-10-10-29W3
K.B 3167'
3
FINA CIGOL
CYPRESS 6-14-11-28
6-14-11-28W3
K.B 3778'
4
HOMSTEAD ET AL
HATTON 7-30
7-30-13-26W3
K.B 2421
5
RIC OAKWOOD
SANDHILLS 10A-32-14-24
10-32-14-24W3
K.B 2351'
6
S.W.S. S BESTVILLE 15-4-16-22
15-4-16-22W3
K.B 2418'
7
CALSTAN BESTVILLE
PROV 4-19-17-21
4-19-17-21W3
K.B 2459'
8
PINN ET AL
SHACKLETON 7-17-20-19
7-17-20-19W3
K.B 2175'
9
TIDE WATER
ABBEY CROWN No. 2
1-31-21-18W3
K.B 1920'
10
C D N SUP ALMINEX
LACADENA 6-21-23-16
6-21-23-16W3
K.B 2047
11
C D N SUP ALMINEX
ELROSE 6-23-14
6-23-23-14W3
K.B 2433
SP
R
DIL
BIG RIVER FORMATION
FISH-SCALE MARKER
STRATIGRAPHIC DATUM
BASE OF SECOND
WHITE-SPECKLED SHALE
VIKING FORMATION
SPINNEY HILL SANDSTONE
MANNVILLE GROUP (PART)
16
SWANSON CROWN No. 1
4-8-32-9W3
K.B.1774
17
PAN AM A 1 WEST
SASKATOON 14-10-35-7
14-10-35-7W3
K.B.1725
18
MIDAS No. 1
4-2-36-4W3
K.B.1722
19
P C A SASKATOON No. 10
4-4-37-3W3
K.B.1782
20
ABERDEEN No. 1
9-6-39-2W3
K.B.1699
21
BRITALTA CARPENTER No. 1
5-30-41-27W2
K.B.1730
22
CAL-STAN GULF
LEOFNARD 13-3-42-26
13-3-42-26W2
K.B.1900
23
BRITALTA PELICAN LAKE No. 1
2-2-44-26W2
K.B.1700
24
CEJA
BIRCH HILLS 4-29-46-24
4-29-46-24W2
K.B.1513
H'
25
B.A. SARRY 13
13-16-47-22W2
K.B.1477
G
N
BIG RIVER FORMATION
FISH-SCALE MARKER
VIKING FORMATION
VIKING FM
STRATIGRAPHIC DATUM
BASE OF SECOND
WHITE-SPECKLED SHALE
BIG RIVER FM.
ST WALBURG SANDSTONE
SPINNEY HILL SANDSTONE
MANNVILLE GROUP (PART)
VERTICAL SCALE
100
75
50
25
0
300 ft
200
100
0

Figu

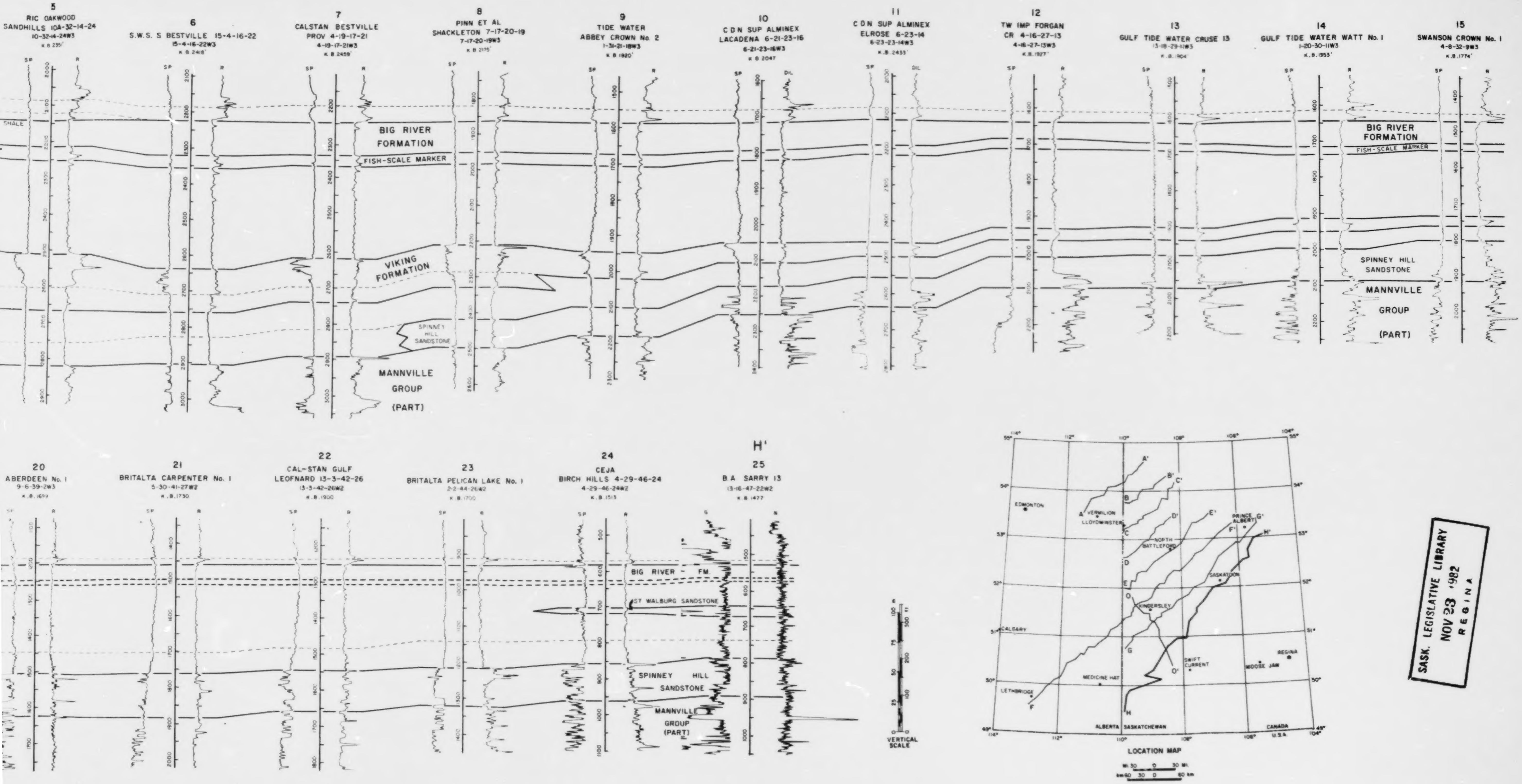

5
RIC OAKWOOD
SANDHILLS 10A-32-14-24
10-32-14-24W3
K B 2351'
6
S.W.S. S BESTVILLE 15-4-16-22
15-4-16-22W3
K B 2418'
7
CALSTAN BESTVILLE
PROV 4-19-17-21
4-19-17-21W3
K B 2459'
8
PINN ET AL
SHACKLETON 7-17-20-19
7-17-20-19W3
K B 2175'
9
TIDE WATER
ABBEY CROWN No. 2
1-31-21-18W3
K B 1920'
10
C D N SUP ALMINEX
LACADENA 6-21-23-16
6-21-23-16W3
K B 2047
11
C D N SUP ALMINEX
ELROSE 6-23-14
6-23-23-14W3
K.B. 2433'
12
TW IMP FORGAN
CR 4-16-27-13
4-16-27-13W3
K.B. 1927'
13
GULF TIDE WATER CRUSE 13
13-18-29-11W3
K.B. 1904'
14
GULF TIDE WATER WATT No. 1
1-20-30-11W3
K.B. 1953'
15
SWANSON CROWN No. 1
4-8-32-9W3
K.B. 1774'
SP
R
DIL
SHALE
BIG RIVER FORMATION
FISH-SCALE MARKER
VIKING FORMATION
SPINNEY HILL SANDSTONE
MANNVILLE GROUP (PART)
H'
20
ABERDEEN No. 1
9-6-39-2W3
K.B. 1699
21
BRITALTA CARPENTER No. 1
5-30-41-27W2
K.B. 1730
22
CAL-STAN GULF
LEOFNARD 13-3-42-26
13-3-42-26W2
K.B. 1900
23
BRITALTA PELICAN LAKE No. 1
2-2-44-26W2
K.B. 1700
24
CEJA
BIRCH HILLS 4-29-46-24
4-29-46-24W2
K.B. 1513
25
B.A SARRY 13
13-16-47-22W2
K.B 1477
G
N
BIG RIVER FM
ST WALBURG SANDSTONE
SPINNEY HILL SANDSTONE
MANNVILLE GROUP (PART)
VERTICAL SCALE
m
ft
LOCATION MAP
EDMONTON
VERMILION
LLOYDMINSTER
NORTH BATTLEFORD
PRINCE ALBERT
SASKATOON
KINDERSLEY
CALGARY
SWIFT CURRENT
MOOSE JAW
REGINA
MEDICINE HAT
LETHBRIDGE
ALBERTA
SASKATCHEWAN
CANADA
U.S.A.
A A' B B' C C' D D' E E' F F' G G' H H' O O'
114° 112° 110° 108° 106° 104°
55° 54° 53° 52° 51° 50° 49°
Mi 30 0 30 Mi
km 60 30 0 60 km

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Figure 14 — Southwest-northeast stratigraphic cross-section H-H' of Lower Colorado strata between the Candel et al Cypress Hills 9-9-6-30 (Lsd 9-9-6-30W3) and BA Sarry 13 (Lsd 13-16-47-22W2) wells.

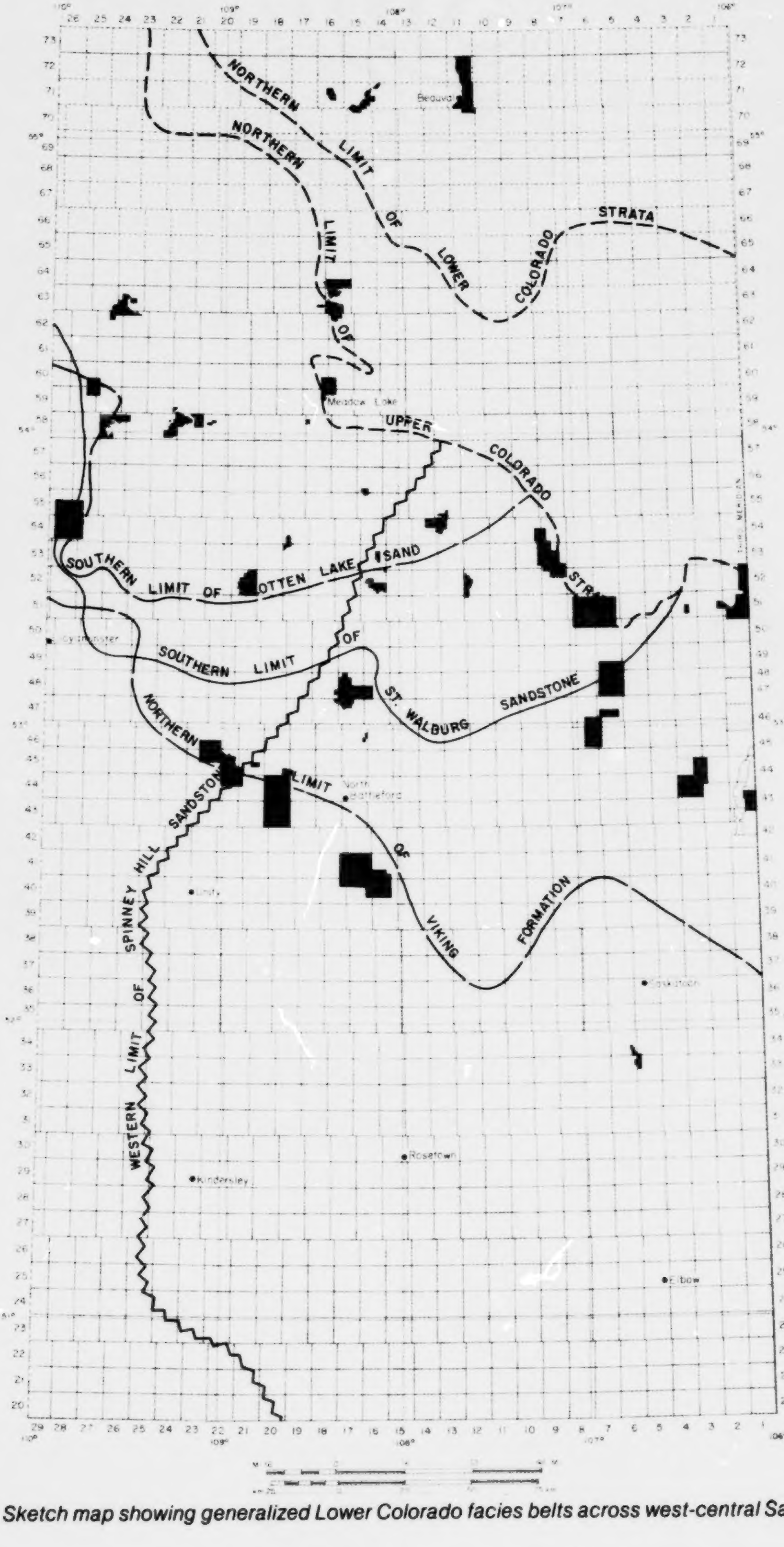

NORTHERN LIMIT OF LOWER COLORADO STRATA
NORTHERN LIMIT OF UPPER COLORADO STRATA
SOUTHERN LIMIT OF COTTEN LAKE SAND
SOUTHERN LIMIT OF ST. WALBURG SANDSTONE
NORTHERN LIMIT OF VIKING FORMATION
WESTERN LIMIT OF SPINNEY HILL SANDSTONE
Beauval
Meadow Lake
Lloydminster
North Battleford
Unity
Saskatoon
Rosetown
Kindersley
Elbow
110°
109°
108°
107°
106°
55°
54°
53°
52°
51°

Figure 15 — Sketch map showing generalized Lower Colorado facies belts across west-central Saskatchewan.

Big River Formation

The unit takes its name from the Big River Provincial Forest region of west-central Saskatchewan, where it exhibits greatest lithologic variation. The type section is from 376 to 447.4 m (1,233.5 to 1,468 ft) in the Duval Saskatoon 6-18-36-6 well (Lsd 6-18-36-6W3). Two incomplete reference sections are also designated: from 105.2 to ca. 180.4 m (345 to ca. 592 ft) in the D.N.R. Flotten Lake No. 2 well (Lsd 4-10-65-17W3) of west-central Saskatchewan and from 334.1 to 352.7 m (1,096 to 1,157 ft) in the Imperial Okla 1-29-35-8 well (Lsd 1-29-35-8W2) of east-central Saskatchewan. The first detailed description of the entire unit is given by Price and Ball, (1971), who referred to it as "unnamed beds", in the Duval Corporation Potash Shaft No. 1 (Lsd 6-18-36-6W3) at Saskatoon, Saskatchewan.

DUVAL SASKATOON 6-18-36-6
Lsd 6-18-36-6W3 KB 506 m (1,659 ft)

BIG RIVER FORMATION

Depth below KB in metres (feet)	
376 - 378 (1,233.5 - 1,240)	Mudstone with scarce siltstone and very fine-grained sandstone intercalations: mudstone dark grey, blocky, frequently silty, micaceous, occasionally slightly glauconitic, as layers up to 8 mm thick but generally less than 1 mm thick with horizontal and very gently inclined laminae, sharp contacts; abundant fish remains often associated with siltstone and sandstone layers.
378 - 378.1 (1,240 - 1,240.5)	Speckled mudstone: dark grey with closely spaced light and very light grey micrite flakes up to coarse sand grade (coccolith aggregates); blocky, laminated.
378.1 - 381.6 (1,240.5 - 1,252)	Mudstone with scarce siltstone and very fine-grained sandstone intercalations: as 376 - 378 m; elongate nodular pyrite concretions up to 25 mm long at 379.8 m; basal 60 cm speckled with micrite flakes.
381.6 - 381.8 (1,252 - 1,252.5)	Speckled mudstone: as 378 - 378.1 m; micrite flakes up to 12 mm long.
381.8 - 384 (1,252.5 - 1,260)	Speckled mudstone with scarce siltstone and very fine-grained sandstone intercalations: as 376 - 378 m; mudstone speckled with micrite flakes.
384 - 386.8 (1,260 - 1,269)	Mudstone with scarce siltstone and very fine-grained sandstone intercalations: as 376 - 378 m.
386.8 - 388.3 (1,269 - 1,274)	Mudstone with numerous siltstone and fine-grained sandstone intercalations: lithologies as 376 - 378 m; siltstone, sandstone light olive grey, yellowish grey, occurring largely as closely spaced flattened lenses and continuous layers up to 25 mm thick with horizontal and gently inclined laminae, sharp contacts, slight upward grading; layering disrupted in places; with *Chondrites*, flattened sand-filled tubular burrows.
388.3 - 391.2 (1,274 - 1,283.5)	Mudstone with scarce siltstone and fine-grained sandstone intercalations: as 376 - 378 m.
391.2 - 392.7 (1,283.5 - 1,288.5)	Mudstone with numerous siltstone and fine-grained sandstone intercalations: as 386.8 - 388.3 m.
392.7 - 397.5 (1,288.5 - 1,304)	Mudstone with scarce siltstone and very fine-grained sandstone intercalations: as 376 - 378 m; speckled from 394.4 m down; finely comminuted fish remains associated with siltstone, sandstone layers.
397.5 - 401.1 (1,304 - 1,316)	Mudstone with numerous siltstone and fine-grained sandstone intercalations: as 386.8 - 388.3 m; sand-filled *Chondrites* networks well developed.
401.1 - 418.2 (1,316 - 1,372)	Mudstone with scarce siltstone and very fine-grained sandstone intercalations: as 376 - 378 m.

418.2 - 419.3 (1,372 - 1,375.5)	Silty sandstone with mudstone partings and intercalations: light olive grey, fine-grained with silt and mud content increasing downward, quartzose, micaceous, slightly glauconitic; in flattened lenses and irregular thin layers, frequently contorted; mudstone medium dark and dark grey, often silty, micaceous, finely laminated; interval top and base both marked by very thin layers of very light grey bentonitic mudstone; with finely comminuted fish skeletal remains, *Chondrites*; mud-filled, sandlined, straight, tubular burrows.
419.3 - 423.8 (1,375.5 - 1,390.5)	Mudstone with scarce siltstone and very fine-grained sandstone intercalations: as 376 - 378 m; at 421.1 m, 15 cm medium light to very light grey bentonitic mudstone, laminated with transitional top, sharp basal contact, bentonite content increasing downward.
423.8 - 424.1 (1,390.5 - 1391.5)	Silty sandstone: as 418.2 - 419.3 m, but with higher sand content.
424.1 - 430.4 (1,391.5 - 1,412)	Alternation of mudstone and siltstone/fine-grained sandstone: mudstone dark grey, frequently silty, micaceous, finely laminated, mud content of interval increases downward; siltstone, sandstone light olive grey, light grey, quartzose, micaceous, slightly glauconitic, as layers up to 10 cm thick with horizontal and gently inclined laminae and ripple-scale cross-laminae, sharp contacts often with sole markings (mostly groove and prod moulds), upward grading; downward decrease in sand content, so that below 427.3 m relatively coarse-grained layers are mostly siltstone; thinner layers frequently contorted; with fish remains, *Chondrites*; mud-filled, sand-lined, straight, tubular burrows.
430.4 - 442.6 (1,412 - 1,452)	Mudstone with siltstone and fine-grained sandstone intercalations: as 386.8 - 388.3 m; with numerous relatively coarse-grained intercalations: 432.2 - 433.4 m; ferruginous very fine-grained silty sandstone at 435.7 m (8 cm), 440 m (15 cm); coalescing nodular pyrite concretions at 432.4 m; core shattered 433.4 - 434.6 m.
442.6 - 443.2 (1,452 - 1,454)	Silty sandstone: light olive grey, very fine-grained, quartzose, micaceous, with numerous interconnected mudstone partings; with *Teichichnus*.
443.2 - 447.4 (1,454 - 1,468)	Mudstone with scarce siltstone and very fine-grained sandstone intercalations: as 376 - 378 m; with fish remains, *Chondrites*, flattened mud-filled, sand-lined, straight, tubular burrows; 15 cm ferruginous very fine-grained silty sandstone at 443.3 m.

DNR FLOTTEN LAKE NO. 2
Lsd 4-10-65-17W3 GL 488 m (1,601 ft)

Depth below GL in metres (feet)

BIG RIVER FORMATION

Big River mudstone

Depth below GL in metres (feet)	
105.2 - 112.8 (345 - 370)	Mudstone with siltstone and scarce very fine-grained sandstone intercalations: mudstone medium dark to dark grey, silty in places, micaceous, finely laminated; siltstone, sandstone medium to light grey, quartzose, micaceous, as flattened lenses; with fish remains.
112.8 - 116.1 (370 - 381)	Silty mudstone with siltstone and scarce very fine-grained sandstone intercalations: as 105.2 - 112.8 m, but with increased siltstone content; fish remains and phosphatic bodies common in places (e.g. ca. 113.2 m), concentrated at erosional lower contacts of thin sandstone layers, with sand-filled straight tubular burrows with longitudinal striations (? *Thalassinoides*); sandstone layers up to 8 mm thick with horizontal and gently inclined laminae, sharp contacts.
116.1 - 135.6 (381 - 445)	Mudstone with siltstone and scarce very fine-grained sandstone: as 105.2 - 112.8 m; basal 6 m very silty; with *Chondrites*.

St. Walburg Sandstone

135.6 - 153.9 (445 - 505)	Silty sandstone: light to medium grey, fine-grained, quartzose, micaceous, slightly glauconitic in places, incorporating closely packed pebble-size pods of disrupted sandstone laminae; flattened tubular burrows, sand-lined, mud-filled; with fish remains (Recovery about 1.2 m).
153.9 - 155.4 (505 - 510)	Sandstone with subordinate mudstone intercalations: sandstone light olive grey to yellowish grey, very poorly indurated, friable, very fine-grained; quartzose, micaceous, glauconitic in places; with horizontal and gently inclined laminae; mudstone silty, micaceous, finely laminated; with siderite impregnation near base (Recovery ca. 23 cm).
155.4 - 163.7 (510 - 537)	Sandstone with subordinate mudstone intercalations: probably as 153.9 - 155.4 m (No recovery; see geological log).

Big River mudstone

163.7 - ca. 180.4 (537 - ca. 592)	Alternation of mudstone and siltstone/very fine-grained sandstone: mudstone medium dark to dark grey, generally silty, micaceous, finely laminated; siltstone, sandstone light olive grey, quartzose, micaceous, horizontally laminated with some upward grading; mud content apparently increases toward base of interval; high kaolinite content at 171.3 m (ca. 15 cm), 172.8 m (ca. 23 cm).

The Big River Formation is composed of dark grey, non-calcareous shale and mudstone of variable fissility, with minor, interbedded, fine and medium-grained sandstone and coarse-grained siltstone. The sandstone and siltstone occur as lenses, commonly a few millimetres thick, and as graded layers, up to several centimetres in thickness, composed of horizontal or very gently inclined laminae. Bioturbated, shaly sandstones and siltstones form relatively scarce layers, up to several centimetres thick. Sand-grade pelecypod debris, notably calcite prisms of *Inoceramus* and fish-skeletal material, form skeletal calcarenites and phosphatic sandstones respectively, which occur commonly in layers similar in structure to those of siliciclastic composition. Thin layers of chert pebbles also occur. Subordinate lithologies include bentonite, nodular phosphorite and concretionary layers of siderite, calcite and pyrite; Price and Ball (1971) have observed veins of barite up to 12 mm wide.

In southern Saskatchewan and southern and central Alberta, the Formation consists chiefly of shales and incorporates the interbedded fish-skeletal sandstones and mudstones of the Fish-Scale Marker, which thins northeastward and is not present in central Saskatchewan. In west-central Saskatchewan to the north of the North Saskatchewan River, the lower half of the Big River Formation includes interbedded kaolinitic and shaly sandstones and non-calcareous mudstone of the northeastward-thickening St. Walburg Sandstone; in east-central Saskatchewan, the unit incorporates kaolinitic sandstone and non-calcareous mudstone of the northward-thickening Okla Sandstone. Elongate megaspores, commonly tightly packed in thin layers, characterize the upper part of the Big River Formation above the Fish-Scale Marker and in stratigraphically equivalent parts of the unit where the latter is not recognized.

The Big River Formation attains a maximum thickness of 150 m in south-western Saskatchewan, thinning to about 42.7 m in east-central Saskatchewan. It also thins markedly in the Rocky Mountain foothills of southern Alberta, where it is replaced to a large extent by the uppermost sandstones of the Bow Island Formation, succeeded by a thick fish-scale sandstone.

The Formation grades into the underlying Bow Island-Viking succession of southern Alberta and western Saskatchewan and the Newcastle-Viking sequence in eastern Saskatchewan. In west-central Saskatchewan, north of the North Saskatchewan River, it is gradational with the underlying Flotten Lake Sand. The Big River Formation is disconformably overlain by calcareous shales and shaly chalks of the Second White-Speckled Shale and equivalent strata. This contact is for the most part sharply defined, and is commonly used as a sub-surface datum. In central Saskatchewan, where the Big River Formation in places is succeeded by a single White-Speckled Shale, the disconformity is particularly pronounced, in that the Fish-Scale unit and overlying Big River shale are not present (Caldwell *et al*, 1978). The appearance of successively younger strata above the disconformity in a progressively basinward direction (North and Caldwell, 1975; Simpson, 1975) further limits the time significance of this correlation surface. In parts of southwestern Saskatchewan, the Big River Formation is overlain by shaly sandstones and siltstones of the Phillips Sandstone. However, in adjacent north-central Montana, the lowermost Phillips lithologies occupy the uppermost part of the Belle Fourche Formation, which together with the underlying Mowry Formation is equivalent to the Big River succession. In southern Manitoba, the Big River sequence is represented by non-calcareous, variably bituminous shales, in the upper part of the Ashville Formation.

The Fish-Scale Marker which splits the Big River section into upper and lower parts is made up of monotonously repeated, light olive grey and olive grey, fine and very fine-grained sandstones and coarse-grained siltstones, up to several centimetres thick, alternating with medium to dark grey, calcareous shales and mudstones of similar thickness. The sandstones and siltstones are graded and composed of crude, horizontal and gently inclined laminae. Fish scales and fragmented fish-skeletal material are abundant, to the degree that they form the main framework component of many graded beds, particularly those located near the base of the unit. Pebbles and granules of chert and nodular phosphorite are found in some graded sandstones. The argillaceous intercalations are finely laminated and incorporate laminae of tightly packed fish scales and fragmented fish-skeletal debris. There is a progressive upward increase in the proportion of intercalated shale and mudstone; in western locations, several fining-upward sequences may be recognized within the unit. Several bentonite layers, each a few centimetres thick, commonly occur. Calcareous concretionary layers with calcite veining are frequently present. Contortions, affecting several graded beds, and sediment-injection structures are common.

The Fish-Scale Marker is widespread in the northern Great Plains region, where it is extensively used as a stratigraphic marker in subsurface correlation. In central and eastern Alberta, southern Saskatchewan and south-western Manitoba, the unit undergoes a gradual northeasterly decrease in thickness from about 21 m in southern locations to 1.5 m or less at the erosional northern limit of the Big River Formation. The *Textularia alcesensis* Zone, which includes the Fish-Scale Marker and most of the overlying *Verneuilinoides perplexus* and *Flaballammina gleddiei* Zones appear to have been removed by erosion in central Saskatchewan (North and Caldwell, 1975).

The boundary between the Upper and Lower Cretaceous appears to be located at the Fish-Scale horizon (Caldwell *et al*, 1978).

St. Walburg Sandstone

The name St. Walburg Sandstone first appeared in the Saskatchewan Department of Mineral Resources Schedule of Wells, Volume 13, for 1963-1964. Although correlations of the unit across west-central Saskatchewan were made by means of geophysical well logs in an unpublished report by Buller and von Ledebur (1962), the first lithologic description was provided by Simpson (1975).

In view of the absence of a complete cored section through the St. Walburg Sandstone, the partial cored sections from two wells are designated reference sections: these are the St. Walburg No. 1 (Lsd 14-31-55-21W3) from 337.1 to 339.2 m and the Cdn. Seaboard Horse Head 9-28-57-18 (Lsd 9-28-57-18W3) from 242.9 to 254.5 m respectively (Fig. 26); the unit is restricted to the subsurface of west-central Saskatchewan.

ST. WALBURG NO. 1
Lsd 14-31-55-21W3 KB 677 m (2,221 ft)

Depth below KB in metres (feet)	
	BIG RIVER FORMATION
	Big River mudstone
302.7 - 303.3 (993 - 995)	Mudstone: dark grey, platy, micaceous and laminated where silty in places; includes at least 2 cm light greenish grey bentonitic mudstone; with fish remains. (Recovery 15 cm).
303.3 - 324 (995 - 1,063)	No core.

324 - 337.1 (1,063 - 1,106)	Mudstone with siltstone intercalations: mudstone dark grey, platy, micaceous and laminated where silty in places, with fish remains and phosphatic bodies throughout but very common in lower 7.6 m; siltstone medium grey, blocky, sandy and friable in places, quartzose, micaceous, with numerous interconnected mudstone partings; burrowed with straight sand-lined, mud-filled tubular forms, *Chondrites*. (Recovery 12.5 m).

St. Walburg Sandstone

337.1 - 339.2 (1,106 - 1,113)	Silty sandstone: light to medium grey, fine-grained, blocky, quartz-rich, micaceous, with numerous interconnected silty mudstone partings; scarce intercalations of very light grey, very fine-grained quartz-rich sandstone with poor induration; interval scarce indeterminate pelecypod debris, fish remains; burrowed, with numerous, straight, sand-lined mud-filled tubular forms, *Chondrites*. (Recovery 1.2 m).
339.2 - 365.8 (1,113 - 1,200)	No core.

Big River mudstone

365.8 - 376.7 (1,200 - 1,236)	Alternation of mudstone and siltstone/very fine-grained sandstone: mudstone predominant, increasing in proportion downward, dark grey, micaceous, and laminated where silty; siltstone, sandstone light olive grey to light grey in layers several cm thick in top 2.7 m, with horizontal and gently inclined laminae, in remainder of interval as flattened lenses and continuous layers up to 2.5 cm thick becoming scarce downward, quartzose, micaceous, slightly glauconitic, with scattered phosphatic bodies and fish remains; ferruginous silty mudstone at 374 m (5 cm), 376.4 m (10 cm), mud and sand-filled tubular burrows, *Chondrites*. (Recovery 7 m).

CDN SEABOARD HORSE HEAD 9-28-57-18

Lsd 9-28-57-18W3 KB 618.1 m (2,028 ft)

Depth below
KB in metres (feet)

BIG RIVER FORMATION

Big River mudstone

231.6 - ca. 233.2 (760 - ca. 765)	Silty mudstone with discontinuous fine-grained sandstone intercalations: mudstone medium light grey, blocky, micaceous, with scattered fine sand grains, with flakes of coalified wood, fish scales, indeterminate ammonite aptychus present, burrowed fairly extensively, flattened tubular burrows subhorizontal with lining of pyrite-impregnated fine sand and mud infilling, mica flakes, wood debris, fish remains concentrated in tube lining. (Recovery about 30 cm).
ca. 233.2 - ca. 235.3 (ca. 765 - ca. 772)	Sandy siltstone: light to medium grey, blocky, micaceous, incorporating often interconnected pebble-size pods of disrupted sandstone laminae; fish scales; burrows as 231.6 - ca. 233.2 m. (Recovery about 46 cm).
ca. 235.3 - 239.6 (ca. 772 - 786)	Silty mudstone with discontinuous fine-grained sandstone intercalations: as 231.6 - ca. 233.2 m. (Recovery about 1.2 m).
239.6 - 241.1 (786 - 791)	Sandy siltstone: as ca. 233.2 - ca. 235.3 m. (Recovery 76 cm).
241.1 - 242.9 (791 - 797)	Silty mudstone with discontinuous fine-grained sandstone intercalations: as 231.6 - ca. 233.2 m. (Recovery 1.5 m).

St. Walburg Sandstone

242.9 - 244.8 (797-803)	Silty sandstone: light to medium grey, fine-grained blocky, micaceous, incorporating closely packed pebble-size pods of disrupted sandstone laminae; fish scales abundant; burrows as 231.6 - ca. 233.2 m, some with longitudinal scratch marks (? *Thalassinoides*), fish remains concentrated in burrows. (Recovery 76 cm).
244.8 - ca. 246.7 (803 - ca. 809.5)	Silty mudstone: as 231.6 - ca. 233.2 m.
ca. 246.7 - ca. 247 (ca. 809.5 - ca. 810.5)	Sandy siltstone: as ca. 233.2 - ca. 235. 3 m.
ca. 247 - 247.5 (ca. 810.5 - 812)	Silty mudstone: as 231.6 - ca. 233.2 m.
247.5 - 248.3 (812 - 814.5)	Silty sandstone: light to medium grey friable, fine to coarse-grained, quartz-rich, micaceous, with numerous interconnected partings of silty mudstone separating lenses of disrupted fine-grained sandstone laminae and irregular bodies of coarser sandstone; scarce scattered pebbles (chert) with black patina; indeterminate shell fragments.
248.3 - 254.5 (814.5 -835)	Sandstone with subordinate silty mudstone intercalations: yellowish grey, very poorly indurated, friable, very fine-grained, quartz-rich, micaceous, in horizontal and inclined laminae, with at least 1 cm bentonitic mudstone at about 248.4 m; burrowed, extensively in places, with straight sand-filled tubular forms, predominantly horizontal and vertical, occasionally branching, some mud-lined. (Recovery about 2.4 m).

The two reference sections are correlated in Fig. 16 and the formation thickness is contoured in Fig. 17.

The St. Walburg Sandstone consists of light to medium grey and light olive grey, fine to coarse-grained silty sandstone with varying proportions of intercalated dark grey mudstone and shale. The sandstones are quartzose, kaolinitic and variably glauconitic. They occur in up to two principal sequences coarsening-upward in sand size and concomitant replacement of alternating layers of sandstone and shale by increasingly bioturbated strata. Scarce conglomerates and pebbly sandstones also occur.

The maximum thickness of the unit is 32.9 m to the north of the town of Meadow Lake. The St. Walburg Sandstone forms a prominent southwestward-thinning wedge, which is restricted to a structural platform, delineated in west-central Saskatchewan by the southern perimeter of the Precambrian Shield and the valley of the modern North Saskatchewan River (Fig. 27).

The St. Walburg Sandstone is conformable with the enveloping shales and mudstones of the Big River Formation. It appears to be the stratigraphic equivalent of Big River shales and mudstones beneath the Fish-Scale unit and is approximately equivalent to the Okla Sandstone of east-central Saskatchewan. Near Meadow Lake, it combines with the Flotten Lake Sand, to form a continuous sandstone succession.

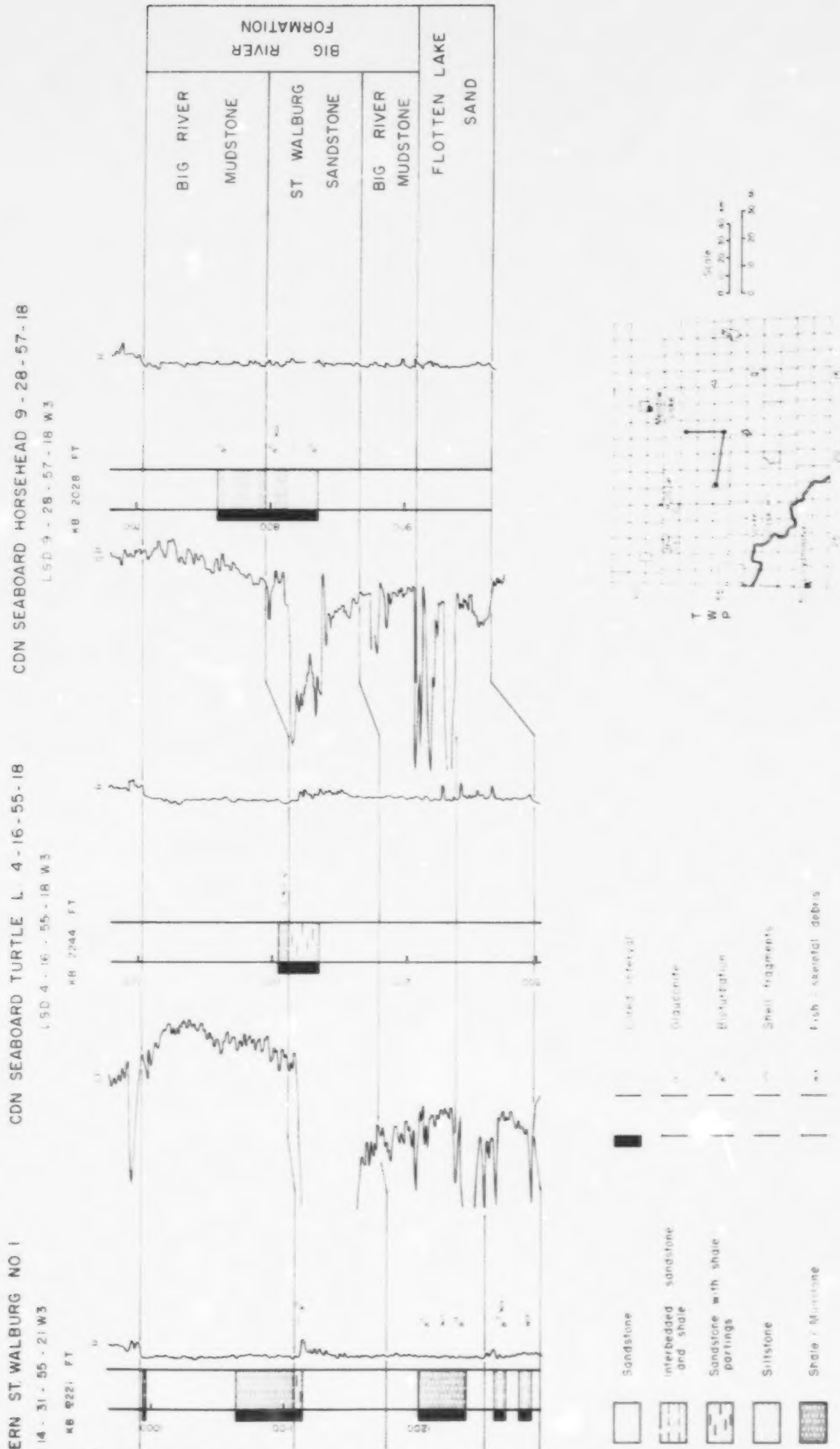

PAN WESTERN ST. WALBURG NO I
LSD 14 - 31 - 55 - 21 W3
KB 922.1 FT
CDN SEABOARD TURTLE L. 4-16-55-18
LSD 4 - 16 - 55 - 18 W3
KB 2244 FT
CDN SEABOARD HORSEHEAD 9-28-57-18
LSD 9 - 28 - 57 - 18 W3
KB 2028 FT
SP
R
BIG RIVER MUDSTONE
ST WALBURG SANDSTONE
BIG RIVER MUDSTONE
FLOTTEN LAKE SAND
BIG RIVER FORMATION
Sandstone
Interbedded sandstone and shale
Sandstone with shale partings
Siltstone
Shale / Mudstone
Cored interval
Glauconite
Bioturbation
Shell fragments
Fish / skeletal debris
TWP
RGE
Scale

Figure 16 — Correlations between type and reference sections for the St. Walburg Sandstone in west-central Saskatchewan.

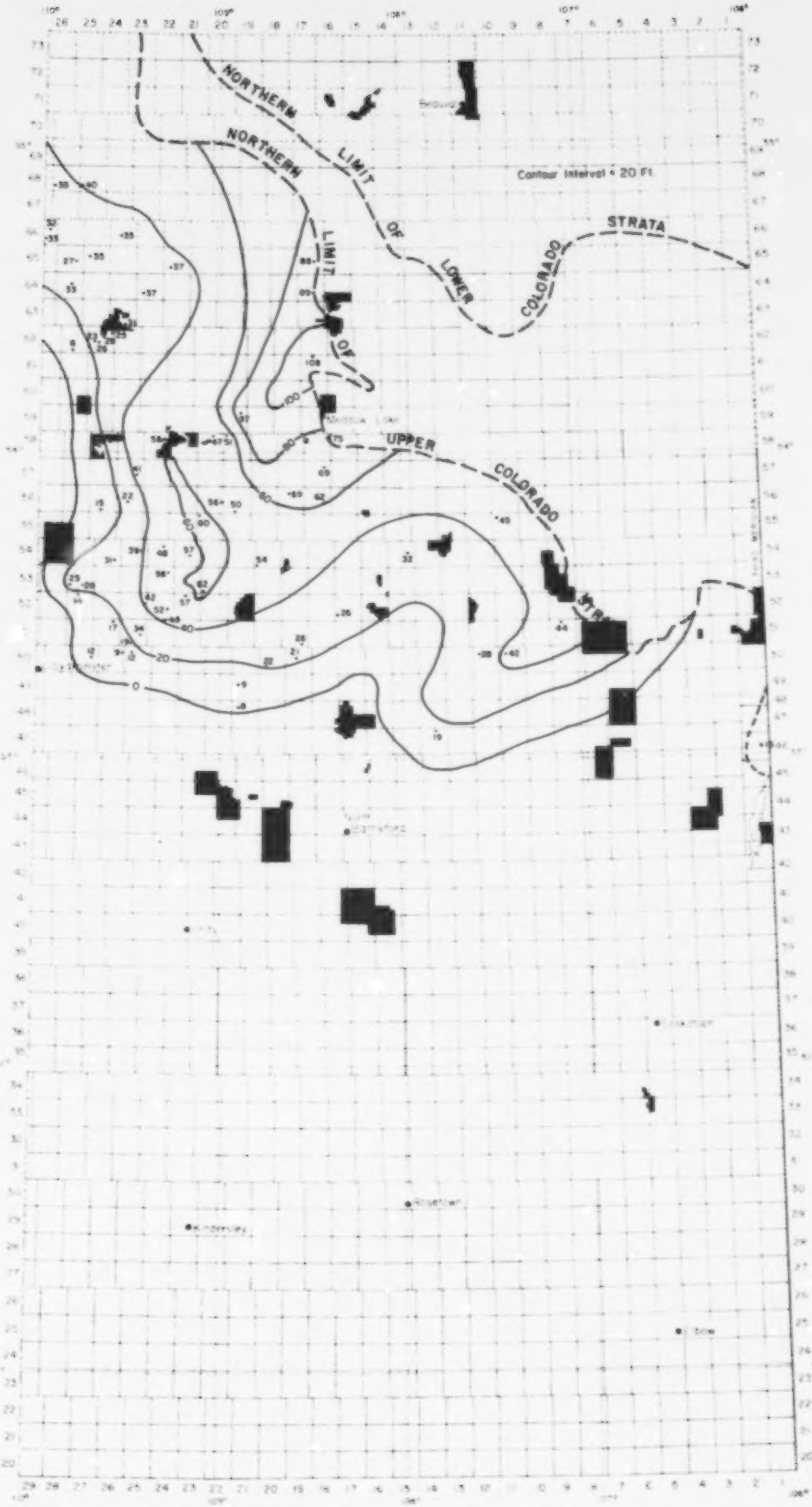

NORTHERN LIMIT OF LOWER COLORADO STRATA
NORTHERN LIMIT OF UPPER COLORADO STRATA
Contour Interval = 20 Ft
Kindersley
Rosetown

Figure 17 — Isopach map of the St. Walburg Sandstone in west-central Saskatchewan.

Viking Formation

No type section has been designated for the Viking Formation. Its name is that given to the producing unit of the Viking-Kinsella field, located near the town of Viking, in southern Alberta.

The Viking Formation consists of relatively well washed and variably shaly, fine to coarse-grained sandstone with subordinate conglomerate and pebbly sandstone. The well washed sandstones are characteristically composed of tabular cross-laminae, but ripple-drift, sinusoidal and trough types and horizontal laminae also occur. The shaly sandstones include both bioturbated deposits several metres thick with variable proportions of mudstone as discontinuous partings and sequences, made up of thin, graded sandstones and siltstones, regularly alternating in vertical succession with thin mudstones and shales. Varicolored chert and reworked-relict, nodular phosphorite and concretionary siderite are noteworthy coarse components of the conglomerates. Their identity is frequently obscured by a dark, brown-black patina. Phosphorized wood and coalified plant fragments are locally common. The mudstones and shales are dark grey and non-calcareous. Bentonites and concretionary layers of siderite are also present. The principal facies are multistory coarsening-upward sandstones in southeastern Alberta and southwestern Saskatchewan, and prominent fining-upward sequences in southeastern Saskatchewan. The composite sandstone bodies are replaced northwards and eastwards by solitary sandstones. The western bodies are locally subdivided into discrete sandstone units alphabetically designated A through D in order of increasing age. At some petroleum-production locales, the formation has been subdivided into members, for example, the Provost and underlying Hamilton Lake Sandstones at the Provost gas field in southeastern Alberta and the Merrington, St. Eloi, Crystal, Hoosier and Smiley Clinobeds (y-o), at the Dodsland-Hoosier production trend in west-central Saskatchewan. In the Wainwright-Westlock production trend of east-central Alberta, Upper, Main and Lower Viking Sandstone units are distinguished. Conglomeratic units within the Viking Formation carry separate names at particular production locales, for example, the Viking Conglomerate of the Wayne-Rosedale gas field in southeastern Alberta and the Viking Chert of the Dodsland-Hoosier trend in west-central Saskatchewan.

The formation extends from central Alberta to southeastern and east-central Saskatchewan. The maximum thickness is in the order of 50 m in eastern Alberta; in southeastern Saskatchewan it is about 40 m. The unit thins to the north and east and pinches out in central Saskatchewan and along the Saskatchewan-Manitoba border.

The western Viking forms the thin, distal part of the northeastward-thinning Bow Island-Viking coarse siliciclastic wedge (Fig. 28). Thus in southwestern Saskatchewan and southern Alberta the Viking Formation is a sequence of sandstones and interbedded mudstones and shales referable to the Bow Island Formation whereas the Viking Formation of southeastern and east-central Saskatchewan appears to display lithological affinities to the Newcastle Formation of North Dakota. The formation grades into mudstones of the overlying Big River Formation. However, in some locations unconformable relations with the underlying Joli Fou Formation can be demonstrated. The eastern Viking strata appear to be stratigraphically higher than the western Viking. The Ashville Sand is the approximately equivalent unit in southern Manitoba, whereas the corresponding sequence in northeastern Alberta is termed the Pelican Sandstone. Likewise Flotten Lake Sand is an equivalent but thickens northeastwards in west-central Saskatchewan.

The cross-section of Fig. 18 displays this northeastward thinning of the sandy wedge from a dominantly arenaceous Lower Colorado succession with clear lithological affinities to the partly equivalent Blackleaf Formation of northwestern Montana (well 1) through a complete succession of Bow Island Sands (well 2), in transition westward to Viking sandstones, of the study area (wells 5, 6 and 7) where they pinch out in the Lloydminster district (well 8). This transition is taken to represent passage from shoreline-nearshore facies (well 5), through proximal (well 6) and distal-shelf (well 7) settings, to distal-shelf and basin (well 8). Isopachs of the Viking Formation (Fig. 19) reflect this and depict the pinch-out of the sandstones immediately south of the North Saskatchewan River.

The Viking shoreline and near-shore facies are displayed in the Oliphant NWRCo Gorefield 7-22-24-26 well (Lsd 7-22-24-26W3).

OLIPHANT NWRCO GOREFIELD 7-22-24-26
Lsd 7-22-24-26W3 KB 683.7 m (2,243 ft)

Depth below KB in metres (feet)	VIKING FORMATION
679.7 - 680.5 (2,230 - 2,232.5)	Sandstone: medium light grey, predominantly fine-grained with scattered coarse sand, quartzose, micaceous, with calcite cement, well indurated, inclined and subordinate horizontal laminae with aligned plant debris, sporadic development of pyrite cement associated with latter; pebble layer at top of interval; burrows scarce, subvertical mud-lined, sand-filled tubes.
680.5 - 692.5 (2,232.5 - 2,272)	Sandstone: as 679.7 - 680.5 m, with downward diminution in grain size, moderate to poor induration; sub-horizontal and inclined, often continuous partings carbonaceous mudstone with abundant coalified plant debris; latter includes well rounded coal pebbles and branched fragments partly pyritized up to 5 cm long and redeposited mud flakes; small-scale trough cross-laminae common; indeterminate scattered shell debris with light brown colour.
692.5 - 707.7 (2,272 - 2,322)	Sandstone: as 679.7 - 680.5 m, but with moderate to poor induration; numerous interconnected mudstone partings and scarce sandy mudstone layers up to 3 cm thick; extensively burrowed, with *Teichichnus*, *Spirophyton*, *Phycodes* and undetermined oblique rhizocorallid burrows, as well as mud-lined sand-filled tubes, both horizontal and vertical.

Figs. 20 to 23 are a series of stratigraphic cross-sections along the depositional slope of the shoreline-nearshore and proximal-shelf facies in the Kindersley district, whereas Figs. 24 and 25 show variation in Viking lithological associations approximately parallel to the depositional strike.

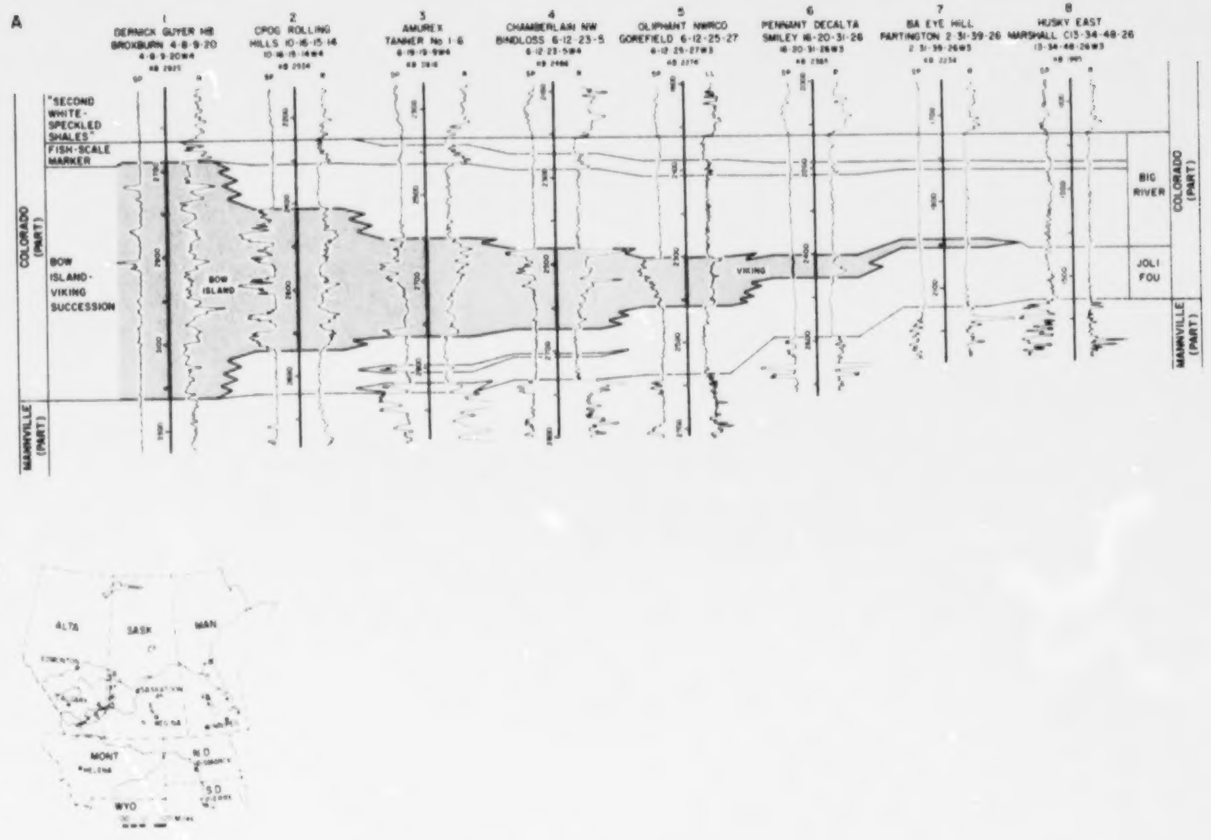
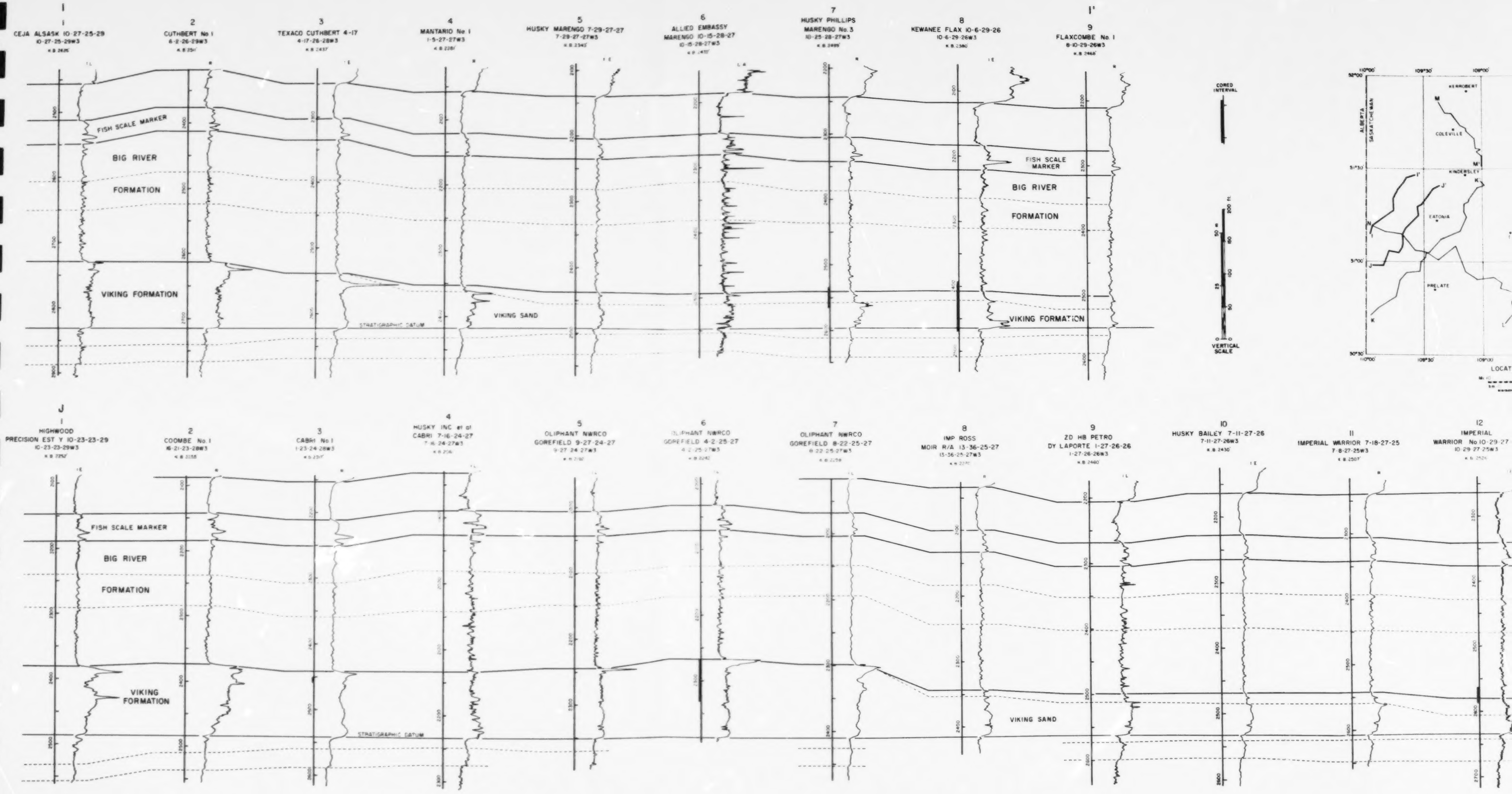
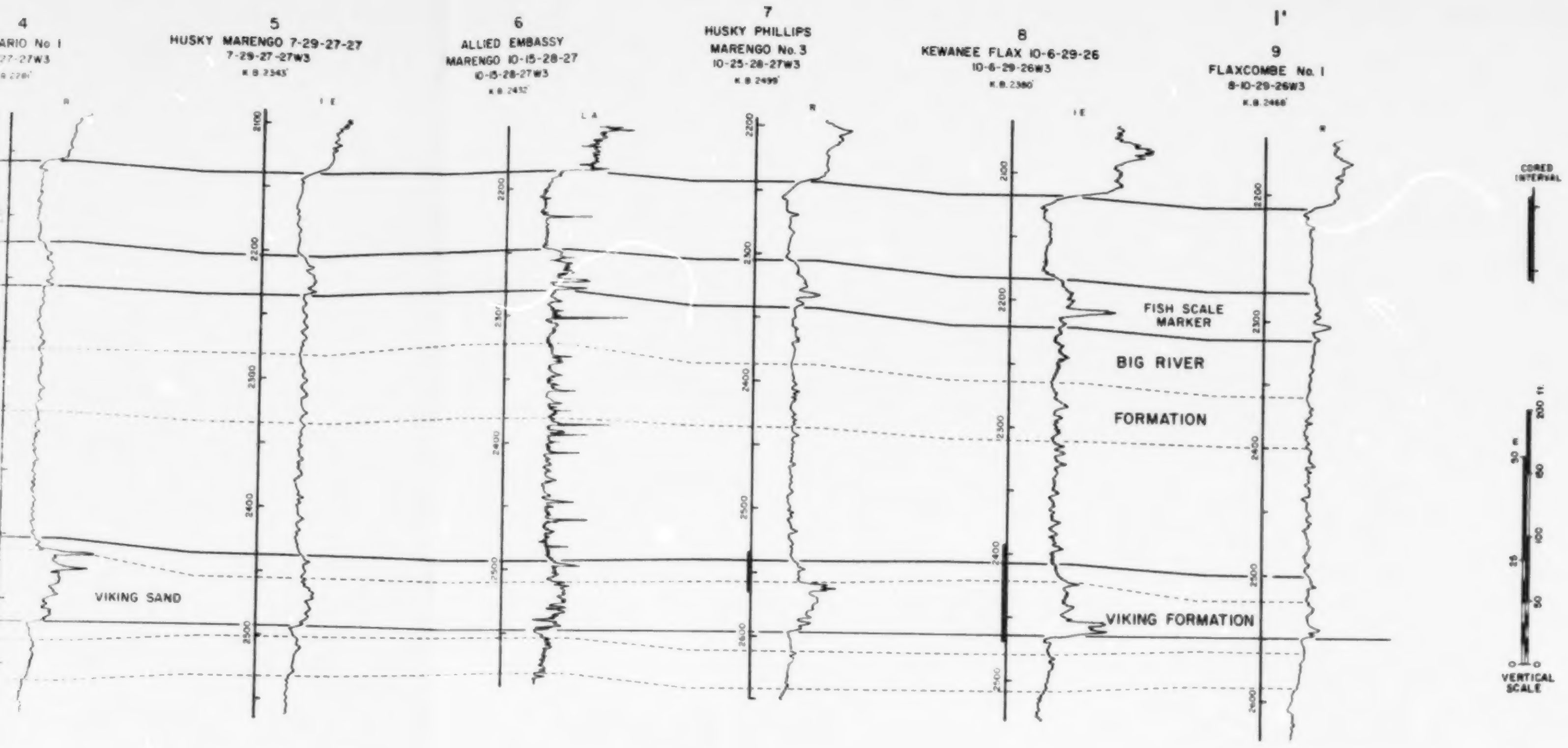

A
1
DERRICK GUYER HB
BROXBURN 4-8-9-20
4-8-9-20W4
2
CPOG ROLLING
HILLS 10-16-15-14
10-16-15-14W4
3
AMUREX
TANNER No 1-6
6-19-19-9W4
4
CHAMBERLAIN NW
BINDLOSS 6-12-23-5
6-12-23-5W4
5
OLIPHANT NWRCO
GOREFIELD 6-12-25-27
6-12-25-27W3
6
PENNANT DECALTA
SMILEY 16-20-31-26
16-20-31-26W3
7
BA EYE HILL
PARTINGTON 2-31-39-26
2-31-39-26W3
8
HUSKY EAST
MARSHALL C13-34-48-26
13-34-48-26W3
SP
R
LL
"SECOND WHITE-SPECKLED SHALES"
FISH-SCALE MARKER
BOW ISLAND-VIKING SUCCESSION
BOW ISLAND
VIKING
BIG RIVER
JOLI FOU
COLORADO (PART)
MANNVILLE (PART)
B
ALTA
SASK
MAN
MONT
N.D.
S.D.
WYO

Figure 18 — Reference wells for Viking lithofacies in west-central Saskatchewan.



I
1
CEJA ALSASK 10-27-25-29
10-27-25-29W3
K.B. 2626'
2
CUTHBERT No. 1
6-2-26-29W3
K.B. 2511'
3
TEXACO CUTHBERT 4-17
4-17-26-28W3
K.B. 2437'
4
MANTARIO No. 1
1-5-27-27W3
K.B. 2281'
5
HUSKY MARENGO 7-29-27-27
7-29-27-27W3
K.B. 2343'
6
ALLIED EMBASSY
MARENGO 10-15-28-27
10-15-28-27W3
7
HUSKY PHILLIPS
MARENGO No. 3
10-25-28-27W3
K.B. 2489'
8
KEWANEE FLAX 10-6-29-26
10-6-29-26W3
K.B. 2380'
I'
9
FLAXCOMBE No. 1
8-10-29-26W3
K.B. 2468'
FISH SCALE MARKER
BIG RIVER
FORMATION
VIKING FORMATION
VIKING SAND
STRATIGRAPHIC DATUM
FISH SCALE MARKER
BIG RIVER
FORMATION
VIKING FORMATION
CORED INTERVAL
50 m
25
0
200 ft
150
100
50
0
VERTICAL SCALE
110°00'
109°30'
109°00'
52°00'
51°30'
51°00'
50°30'
ALBERTA
SASKATCHEWAN
KERROBERT
COLEVILLE
KINDERSLEY
EATONIA
PRELATE
M
M'
I
I'
J
J'
K
K'
N
L'
LOCAT
J
1
HIGHWOOD
PRECISION EST Y 10-23-23-29
10-23-23-29W3
K.B. 2252'
2
COOMBE No. 1
16-21-23-28W3
K.B. 2238
3
CABRI No. 1
1-23-24-28W3
K.B. 2317'
4
HUSKY INC et al
CABRI 7-16-24-27
7-16-24-27W3
5
OLIPHANT NWRCO
GOREFIELD 9-27-24-27
9-27-24-27W3
6
OLIPHANT NWRCO
GOREFIELD 4-2-25-27
4-2-25-27W3
K.B. 2242
7
OLIPHANT NWRCO
GOREFIELD 8-22-25-27
8-22-25-27W3
8
IMP ROSS
MOIR R/A 13-36-25-27
13-36-25-27W3
K.B. 2270
9
ZD HB PETRO
DY LAPORTE 1-27-26-26
1-27-26-26W3
K.B. 2460'
10
HUSKY BAILEY 7-11-27-26
7-11-27-26W3
K.B. 2430'
11
IMPERIAL WARRIOR 7-18-27-25
7-8-27-25W3
K.B. 2507'
12
IMPERIAL
WARRIOR No 10-29-27
10-29-27-25W3
FISH SCALE MARKER
BIG RIVER
FORMATION
VIKING
FORMATION
VIKING SAND
STRATIGRAPHIC DATUM

Figure 21 — Southwest-northe
Highwood Precisi
8-19-28-24W3) we


4
ARIO No 1
27-27W3
5
HUSKY MARENGO 7-29-27-27
7-29-27-27W3
K.B. 2343'
6
ALLIED EMBASSY
MARENGO 10-15-28-27
10-15-28-27W3
K.B. 2432'
7
HUSKY PHILLIPS
MARENGO No. 3
10-25-28-27W3
K.B. 2499'
8
KEWANEE FLAX 10-6-29-26
10-6-29-26W3
K.B. 2380'
I'
9
FLAXCOMBE No. 1
8-10-29-26W3
K.B. 2468'
CORED INTERVAL
FISH SCALE MARKER
BIG RIVER
FORMATION
VIKING SAND
VIKING FORMATION
VERTICAL SCALE
50 m
200 ft

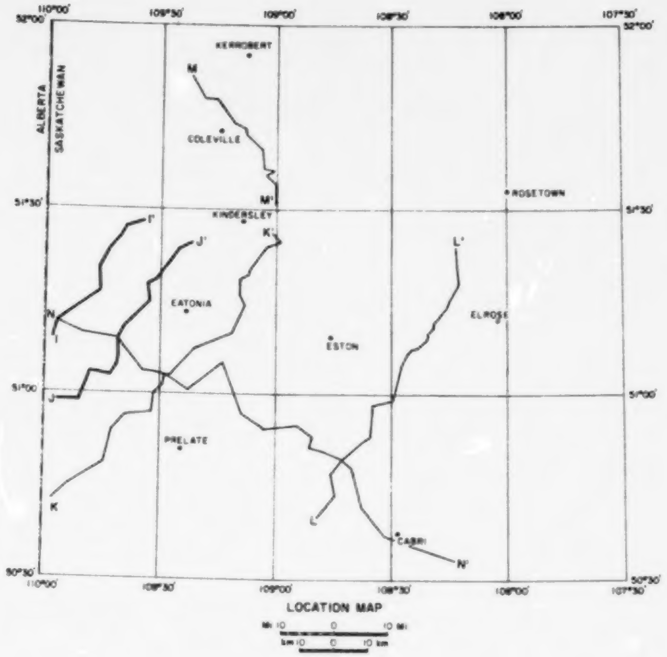

110°00'
109°30'
109°00'
108°30'
108°00'
107°30'
52°00'
51°30'
51°00'
50°30'
ALBERTA
SASKATCHEWAN
KERROBERT
COLEVILLE
KINDERSLEY
ROSETOWN
EATONIA
ESTON
ELROSE
PRELATE
CABRI
M
M'
I
I'
J
J'
K
K'
L
L'
N
N'
LOCATION MAP
Mi 10 0 10 Mi
km 10 0 10 km

Figure 20 — Southwest-northeast stratigraphic cross-section I-I' of Viking and Big River strata between the Ceja Alsask 10-27-25-29 (Lsd 10-27-25-29W3) and Flaxcombe No. 1 (Lsd 8-10-29-26W3) wells.

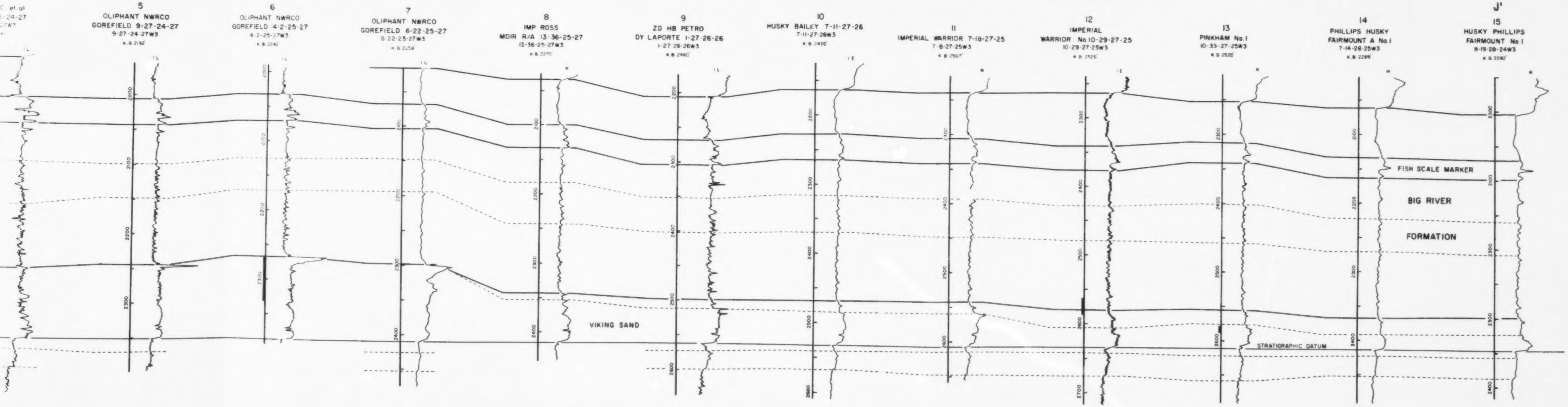
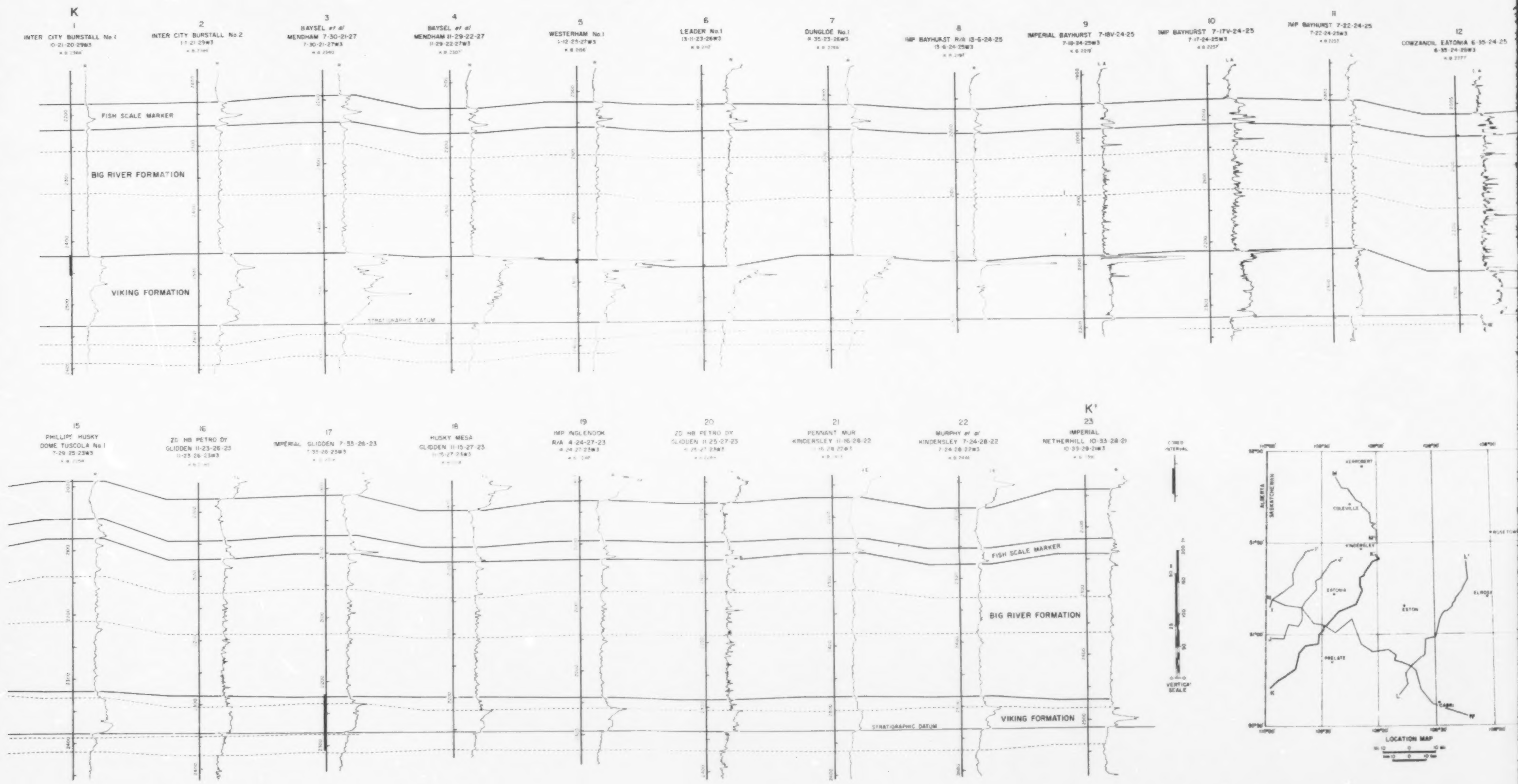
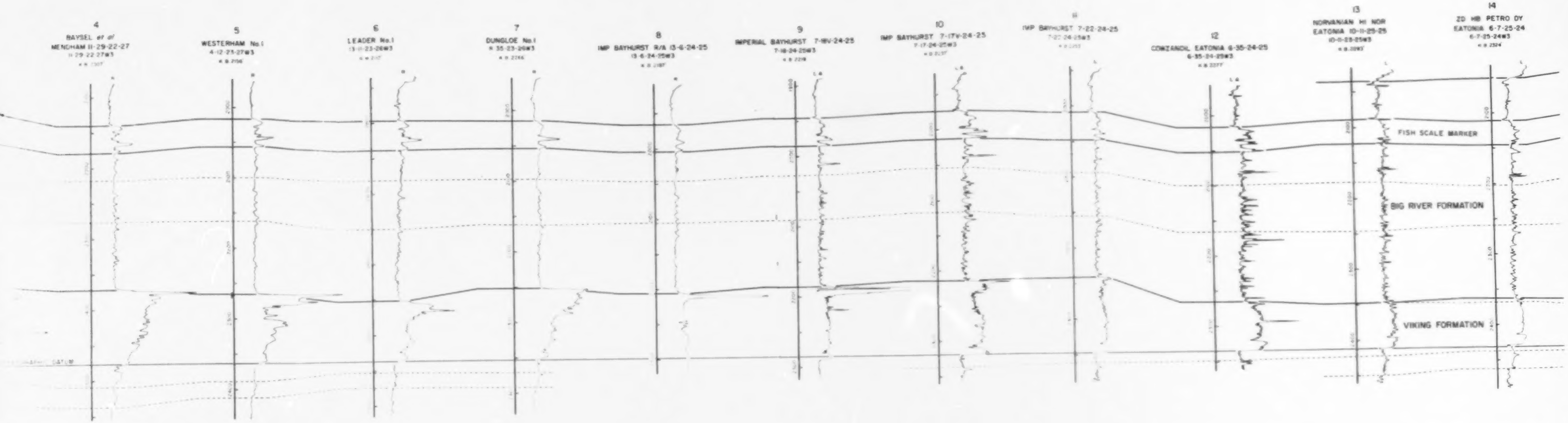

4
C et al
-24-27
-27W3
5
OLIPHANT NWRCO
GOREFIELD 9-27-24-27
9-27-24-27W3
K.B. 2192'
6
OLIPHANT NWRCO
GOREFIELD 4-2-25-27
4-2-25-27W3
K.B. 2242
7
OLIPHANT NWRCO
GOREFIELD 8-22-25-27
8-22-25-27W3
K.B. 2259'
8
IMP ROSS
MOIR R/A 13-36-25-27
13-36-25-27W3
K.B. 2270'
9
ZD HB PETRO
DY LAPORTE 1-27-26-26
1-27-26-26W3
K.B. 2460'
10
HUSKY BAILEY 7-11-27-26
7-11-27-26W3
K.B. 2430'
11
IMPERIAL WARRIOR 7-18-27-25
7-8-27-25W3
K.B. 2507'
12
IMPERIAL
WARRIOR No. 10-29-27-25
10-29-27-25W3
K.B. 2526'
13
PINKHAM No. 1
10-33-27-25W3
K.B. 2520'
14
PHILLIPS HUSKY
FAIRMOUNT A No. 1
7-14-28-25W3
K.B. 2285'
J'
15
HUSKY PHILLIPS
FAIRMOUNT No. 1
8-19-28-24W3
K.B. 2282'
FISH SCALE MARKER
BIG RIVER
FORMATION
VIKING SAND
STRATIGRAPHIC DATUM

Figure 21 — Southwest-northeast stratigraphic cross-section J-J' of Viking and Big River strata between the Highwood Precision Est Y 10-23-23-29 (Lsd 10-23-23-29W3) and Husky Phillips Fairmount No. 1 (Lsd 8-19-28-24W3) wells.


K
1
INTER CITY BURSTALL No.1
10-21-20-29W3
2
INTER CITY BURSTALL No.2
1-1-21-29W3
3
BAYSEL et al
MENDHAM 7-30-21-27
7-30-21-27W3
4
BAYSEL et al
MENDHAM 11-29-22-27
11-29-22-27W3
5
WESTERHAM No.1
-12-23-27W3
6
LEADER No.1
13-11-23-26W3
7
DUNGLOE No.1
-35-23-26W3
8
IMP BAYHURST R/A 13-6-24-25
13-6-24-25W3
9
IMPERIAL BAYHURST 7-18V-24-25
7-18-24-25W3
10
IMP BAYHURST 7-17V-24-25
7-17-24-25W3
11
IMP BAYHURST 7-22-24-25
7-22-24-25W3
12
COWZANOIL EATONIA 6-35-24-25
6-35-24-25W3
FISH SCALE MARKER
BIG RIVER FORMATION
VIKING FORMATION
STRATIGRAPHIC DATUM
15
PHILLIPS HUSKY
DOME TUSCOLA No.1
7-29-25-23W3
16
ZD HB PETRO DY
GLIDDEN 11-23-26-23
11-23-26-23W3
17
IMPERIAL GLIDDEN 7-33-26-23
7-33-26-23W3
18
HUSKY MESA
GLIDDEN 11-15-27-23
11-15-27-23W3
19
IMP INGLENOOK
R/A 4-24-27-23
4-24-27-23W3
20
ZD HB PETRO DY
GLIDDEN 11-25-27-23
11-25-27-23W3
21
PENNANT MUR
KINDERSLEY 11-16-28-22
11-16-28-22W3
22
MURPHY et al
KINDERSLEY 7-24-28-22
7-24-28-22W3
K'
23
IMPERIAL
NETHERHILL 10-33-28-21
10-33-28-21W3
FISH SCALE MARKER
BIG RIVER FORMATION
VIKING FORMATION
STRATIGRAPHIC DATUM
CORED INTERVAL
VERTICAL SCALE
ALBERTA
SASKATCHEWAN
KERROBERT
COLEVILLE
KINDERSLEY
EATONIA
ESTON
ELROSE
PRELATE
CABRI
ROSETOWN
M
M'
I
I'
J
J'
K
K'
L
L'
LOCATION MAP


4
BAYSEL et al
MENDHAM 11-29-22-27
11-29-22-27W3
5
WESTERHAM No.1
4-12-23-27W3
6
LEADER No.1
13-11-23-26W3
7
DUNGLOE No.1
8-35-23-26W3
8
IMP BAYHURST R/A 13-6-24-25
13-6-24-25W3
9
IMPERIAL BAYHURST 7-18V-24-25
7-18-24-25W3
10
IMP BAYHURST 7-17V-24-25
7-17-24-25W3
11
IMP BAYHURST 7-22-24-25
7-22-24-25W3
12
CONZANDIL EATONIA 6-35-24-25
6-35-24-25W3
13
NORVANIAN HI NOR
EATONIA 10-11-25-25
10-11-25-25W3
14
ZD HB PETRO DY
EATONIA 6-7-25-24
6-7-25-24W3
FISH SCALE MARKER
BIG RIVER FORMATION
VIKING FORMATION
STRATIGRAPHIC DATUM

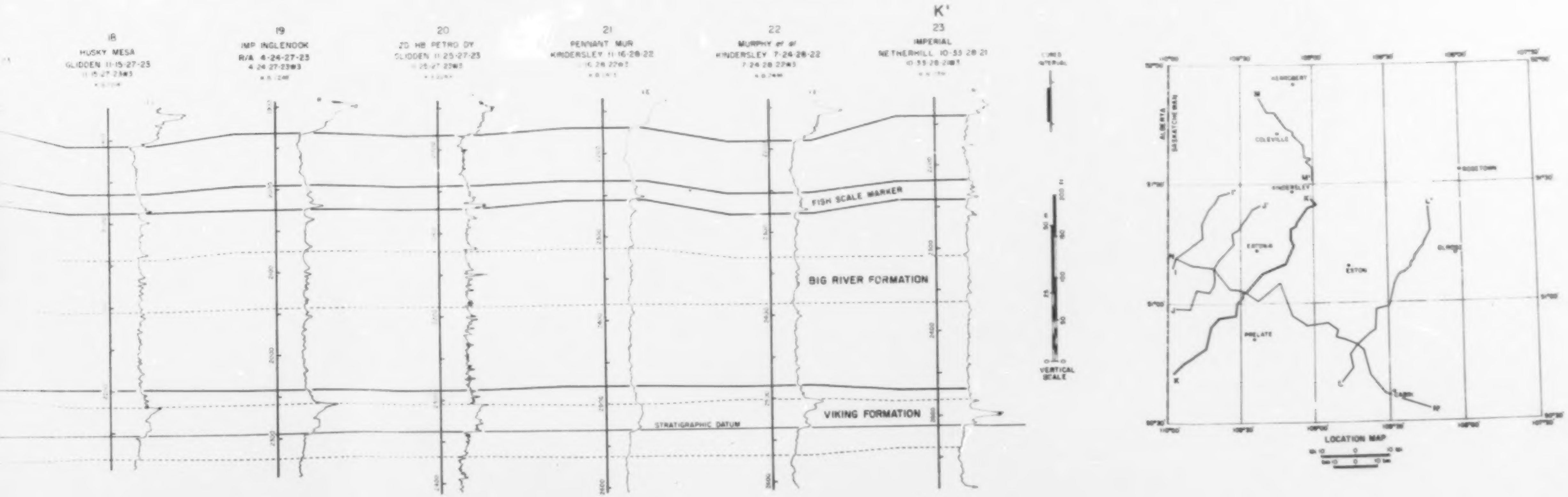

K'
18
HUSKY MESA
GLIDDEN 11-15-27-23
11-15-27-23W3
19
IMP INGLENOOK
R/A 4-24-27-23
4-24-27-23W3
20
ZD HB PETRO DY
GLIDDEN 11-25-27-23
11-25-27-23W3
21
PENNANT MUR
KINDERSLEY 11-16-28-22
11-16-28-22W3
22
MURPHY et al
KINDERSLEY 7-24-28-22
7-24-28-22W3
23
IMPERIAL
NETHERHILL 10-33-28-21
10-33-28-21W3
FISH SCALE MARKER
BIG RIVER FORMATION
VIKING FORMATION
STRATIGRAPHIC DATUM
VERTICAL SCALE
ALBERTA
SASKATCHEWAN
KERROBERT
COLEVILLE
KINDERSLEY
ROSETOWN
EATONIA
ESTON
ELROSE
PRELATE
LOCATION MAP

Figure 22 — Southwest-northeast stratigraphic cross-section K-K' of Viking and Big River strata between the Inter City Burstall No. 1 (Lsd 10-21-20-29W3) and Imperial Netherhill 10-33-28-21 (Lsd 10-33-28-21W3) wells.

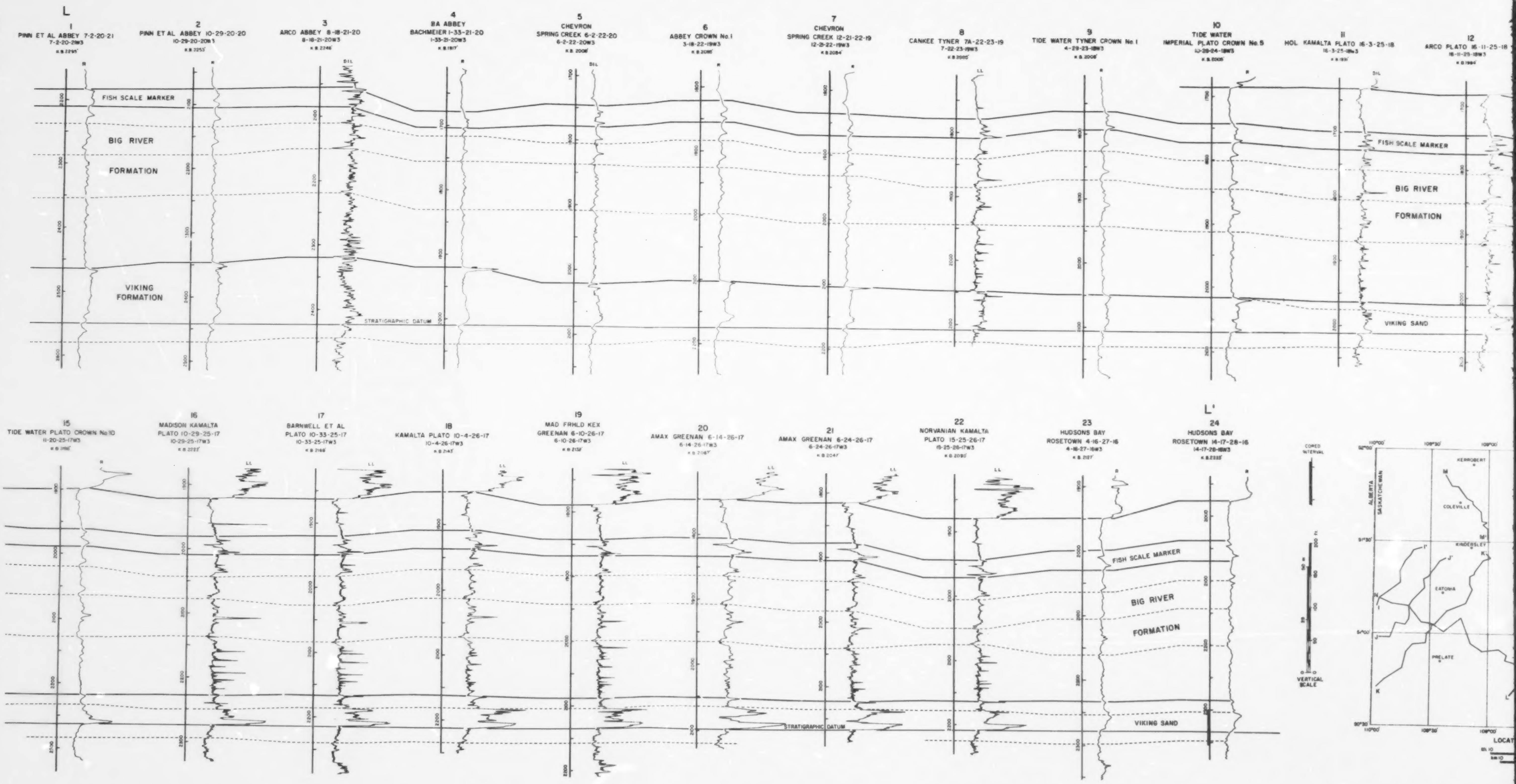

L
1
PINN ET AL ABBEY 7-2-20-21
7-2-20-21W3
K.B.2295'
2
PINN ET AL ABBEY 10-29-20-20
10-29-20-20W3
K.B.2253'
3
ARCO ABBEY 8-18-21-20
8-18-21-20W3
K.B.2246'
4
BA ABBEY
BACHMEIER 1-33-21-20
1-33-21-20W3
K.B.1917'
5
CHEVRON
SPRING CREEK 6-2-22-20
6-2-22-20W3
K.B.2008'
6
ABBEY CROWN No.1
3-18-22-19W3
K.B.2085'
7
CHEVRON
SPRING CREEK 12-21-22-19
12-21-22-19W3
K.B.2084'
8
CANKEE TYNER 7A-22-23-19
7-22-23-19W3
K.B.2005'
9
TIDE WATER TYNER CROWN No.1
4-29-23-18W3
K.B.2008'
10
TIDE WATER
IMPERIAL PLATO CROWN No.5
13-28-24-18W3
K.B.2005'
11
HOL KAMALTA PLATO 16-3-25-18
16-3-25-18W3
K.B.1931'
12
ARCO PLATO 16-11-25-18
16-11-25-18W3
K.B.1994'
R
DIL
LL
FISH SCALE MARKER
BIG RIVER
FORMATION
VIKING
FORMATION
STRATIGRAPHIC DATUM
VIKING SAND
15
TIDE WATER PLATO CROWN No.10
11-20-25-17W3
K.B.2116'
16
MADISON KAMALTA
PLATO 10-29-25-17
10-29-25-17W3
K.B.2221'
17
BARNWELL ET AL
PLATO 10-33-25-17
10-33-25-17W3
K.B.2168'
18
KAMALTA PLATO 10-4-26-17
10-4-26-17W3
K.B.2143'
19
MAD FRHLD KEX
GREENAN 6-10-26-17
6-10-26-17W3
K.B.2132'
20
AMAX GREENAN 6-14-26-17
6-14-26-17W3
K.B.2067'
21
AMAX GREENAN 6-24-26-17
6-24-26-17W3
K.B.2047'
22
NORVANIAN KAMALTA
PLATO 15-25-26-17
15-25-26-17W3
K.B.2090'
23
HUDSONS BAY
ROSETOWN 4-16-27-16
4-16-27-16W3
K.B.2127'
L'
24
HUDSONS BAY
ROSETOWN 14-17-28-16
14-17-28-16W3
K.B.2333'
CORED INTERVAL
VERTICAL SCALE
200 ft
50 m
ALBERTA
SASKATCHEWAN
110°00'
109°30'
109°00'
52°00'
51°30'
51°00'
50°30'
KERROBERT
COLEVILLE
KINDERSLEY
EATONIA
PRELATE
M
M'
I'
J'
K'
N
I
J
K
LOCAT

Figure 23 — Southwest-northeast stratig
et al Abbey 7-2-20-21 (Lsd 7
14-17-28-16W3) wells.

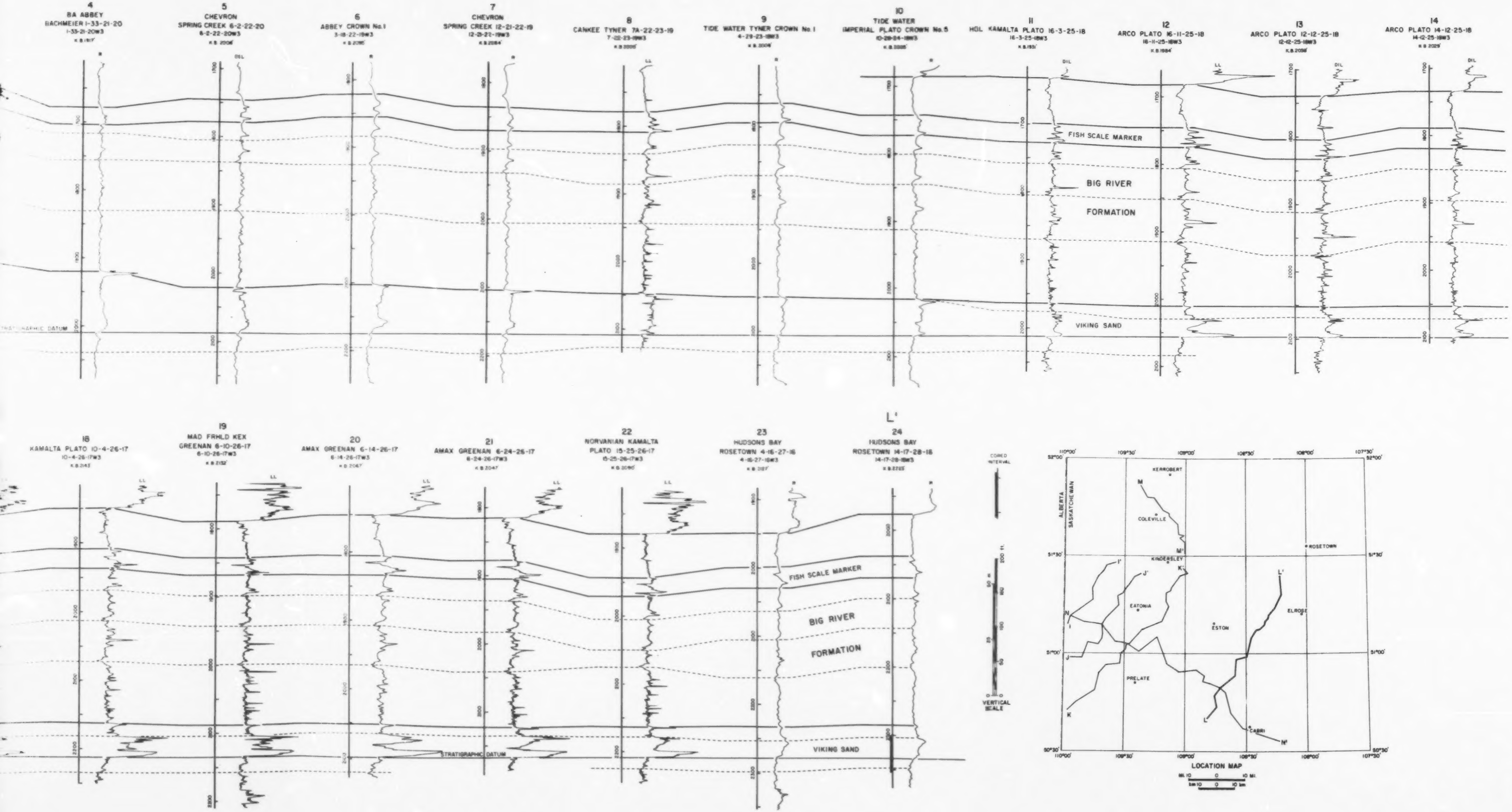
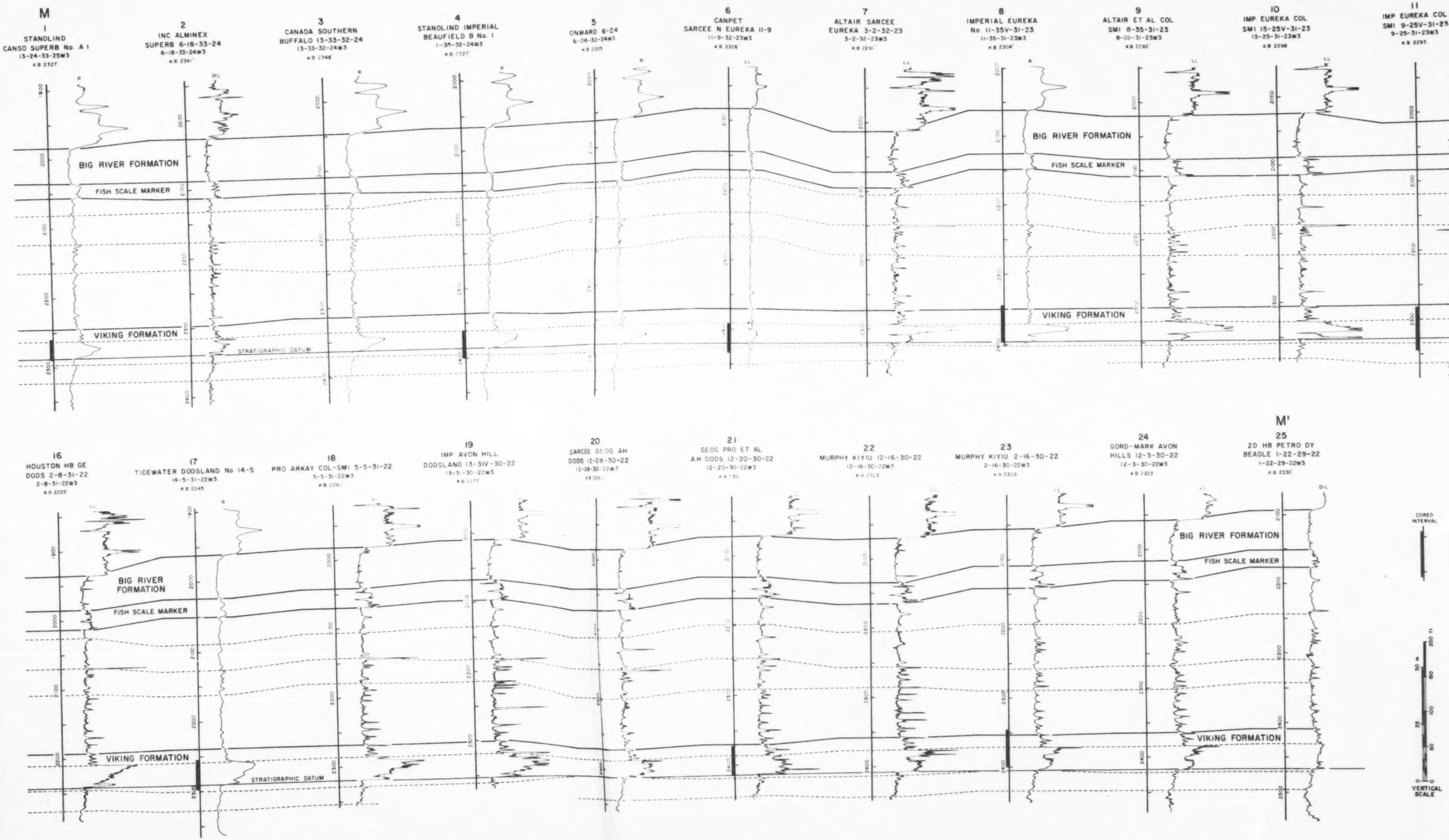
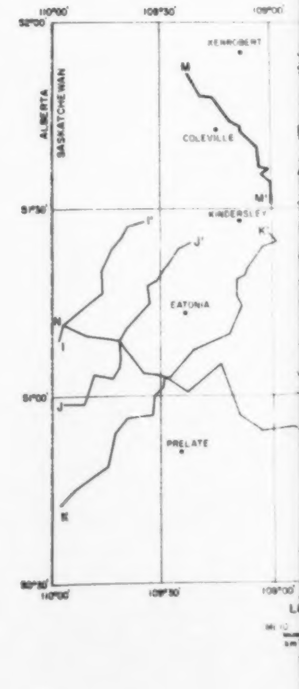

4
BA ABBEY
BACHMEIER 1-33-21-20
1-33-21-20W3
5
CHEVRON
SPRING CREEK 6-2-22-20
6-2-22-20W3
6
ABBEY CROWN No.1
3-18-22-19W3
7
CHEVRON
SPRING CREEK 12-21-22-19
12-21-22-19W3
8
CANKEE TYNER 7A-22-23-19
7-22-23-19W3
9
TIDE WATER TYNER CROWN No.1
4-29-23-18W3
10
TIDE WATER
IMPERIAL PLATO CROWN No.5
10-29-24-18W3
11
HOL KAMALTA PLATO 16-3-25-18
16-3-25-18W3
12
ARCO PLATO 16-11-25-18
16-11-25-18W3
13
ARCO PLATO 12-12-25-18
12-12-25-18W3
14
ARCO PLATO 14-12-25-18
14-12-25-18W3
FISH SCALE MARKER
BIG RIVER
FORMATION
VIKING SAND
STRATIGRAPHIC DATUM
18
KAMALTA PLATO 10-4-26-17
10-4-26-17W3
19
MAD FRHLD KEX
GREENAN 6-10-26-17
6-10-26-17W3
20
AMAX GREENAN 6-14-26-17
6-14-26-17W3
21
AMAX GREENAN 6-24-26-17
6-24-26-17W3
22
NORVANIAN KAMALTA
PLATO 15-25-26-17
15-25-26-17W3
L'
23
HUDSONS BAY
ROSETOWN 4-16-27-16
4-16-27-16W3
24
HUDSONS BAY
ROSETOWN 14-17-28-16
14-17-28-16W3
CORED INTERVAL
VERTICAL SCALE
ALBERTA
SASKATCHEWAN
KERROBERT
COLEVILLE
KINDERSLEY
ROSETOWN
EATONIA
ESTON
ELROSE
PRELATE
CABRI
LOCATION MAP

Figure 23 — Southwest-northeast stratigraphic cross-section L-L' of Viking and Big River strata between the Pinn et al Abbey 7-2-20-21 (Lsd 7-2-20-21W3) and Hudson's Bay Rosetown 14-17-28-16 (Lsd 14-17-28-16W3) wells.


M
1 STANOLIND CANSO SUPERB No. A 1 13-24-33-25W3 KB 2327'
2 INC ALMINEX SUPERB 6-18-33-24 6-18-33-24W3 KB 2341'
3 CANADA SOUTHERN BUFFALO 13-33-32-24 13-33-32-24W3 KB 2348'
4 STANOLIND IMPERIAL BEAUFIELD B No. 1 1-35-32-24W3 KB 2327'
5 ONWARD 6-24 6-24-32-24W3 KB 2325
6 CANPET SARCEE N EUREKA 11-9 11-9-32-23W3 KB 2326'
7 ALTAIR SARCEE EUREKA 3-2-32-23 3-2-32-23W3 KB 2291'
8 IMPERIAL EUREKA No. 11-35V-31-23 11-35-31-23W3 KB 2304'
9 ALTAIR ET AL COL SMI 8-35-31-23 8-35-31-23W3 KB 2292'
10 IMP EUREKA COL SMI 15-25V-31-23 15-25-31-23W3 KB 2298
11 IMP EUREKA COL SMI 9-25V-31-23 9-25-31-23W3 KB 2293
12 ALTAIR ET AL COL SMI 4-30-31-22 4-30-31-22W3 KB 2287
16 HOUSTON HB GE DODS 2-8-31-22 2-8-31-22W3 KB 2225
17 TIDEWATER DODSLAND No 14-5 14-5-31-22W3 KB 2245
18 PRO ARKAY COL-SMI 5-5-31-22 5-5-31-22W3 KB 2261
19 IMP AVON HILL DODSLAND 13-31V-30-22 13-31-30-22W3 KB 2277
20 SARCEE GEOG AH DODS 12-28-30-22 12-28-30-22W3 KB 2261
21 GEOG PRO ET AL AH DODS 12-20-30-22 12-20-30-22W3 KB 2321
22 MURPHY KIYIU 12-16-30-22 12-16-30-22W3 KB 2323
23 MURPHY KIYIU 2-16-30-22 2-16-30-22W3 KB 2309
24 GORD-MARK AVON HILLS 12-3-30-22 12-3-30-22W3 KB 2323
M'
25 ZD HB PETRO DY BEADLE 1-22-29-22 1-22-29-22W3 KB 2330'
R
DIL
LL
BIG RIVER FORMATION
FISH SCALE MARKER
VIKING FORMATION
STRATIGRAPHIC DATUM
1900
2000
2100
2200
2300
2400
2500
CORED INTERVAL
VERTICAL SCALE
0
25
50
100
150
200 ft
50 m

110°00'
109°30'
109°00'
52°00'
51°30'
51°00'
50°30'
ALBERTA
SASKATCHEWAN
KERROBERT
COLEVILLE
KINDERSLEY
EATONIA
PRELATE
M
M'
I
I'
J
J'
K
K'
N

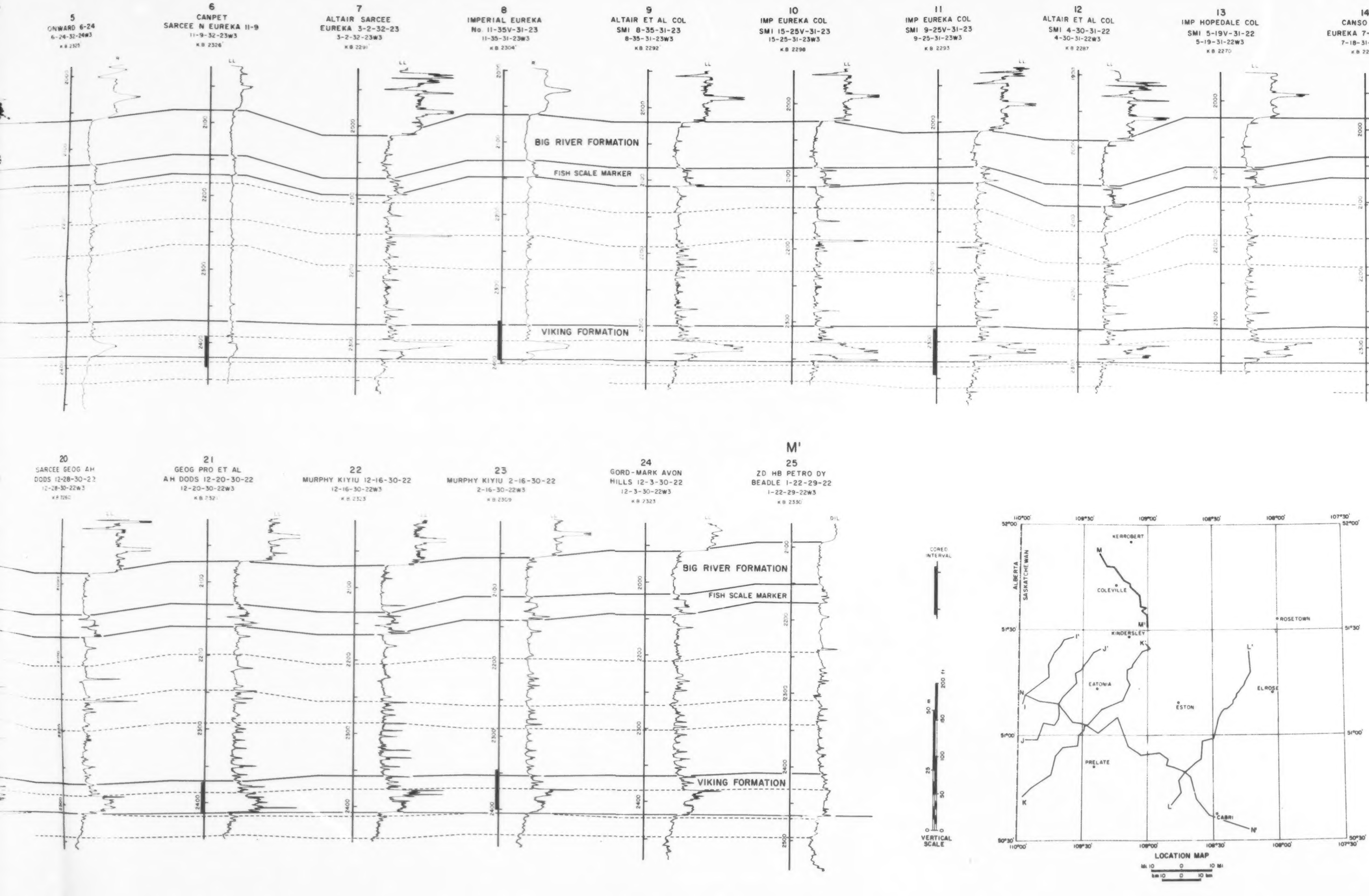
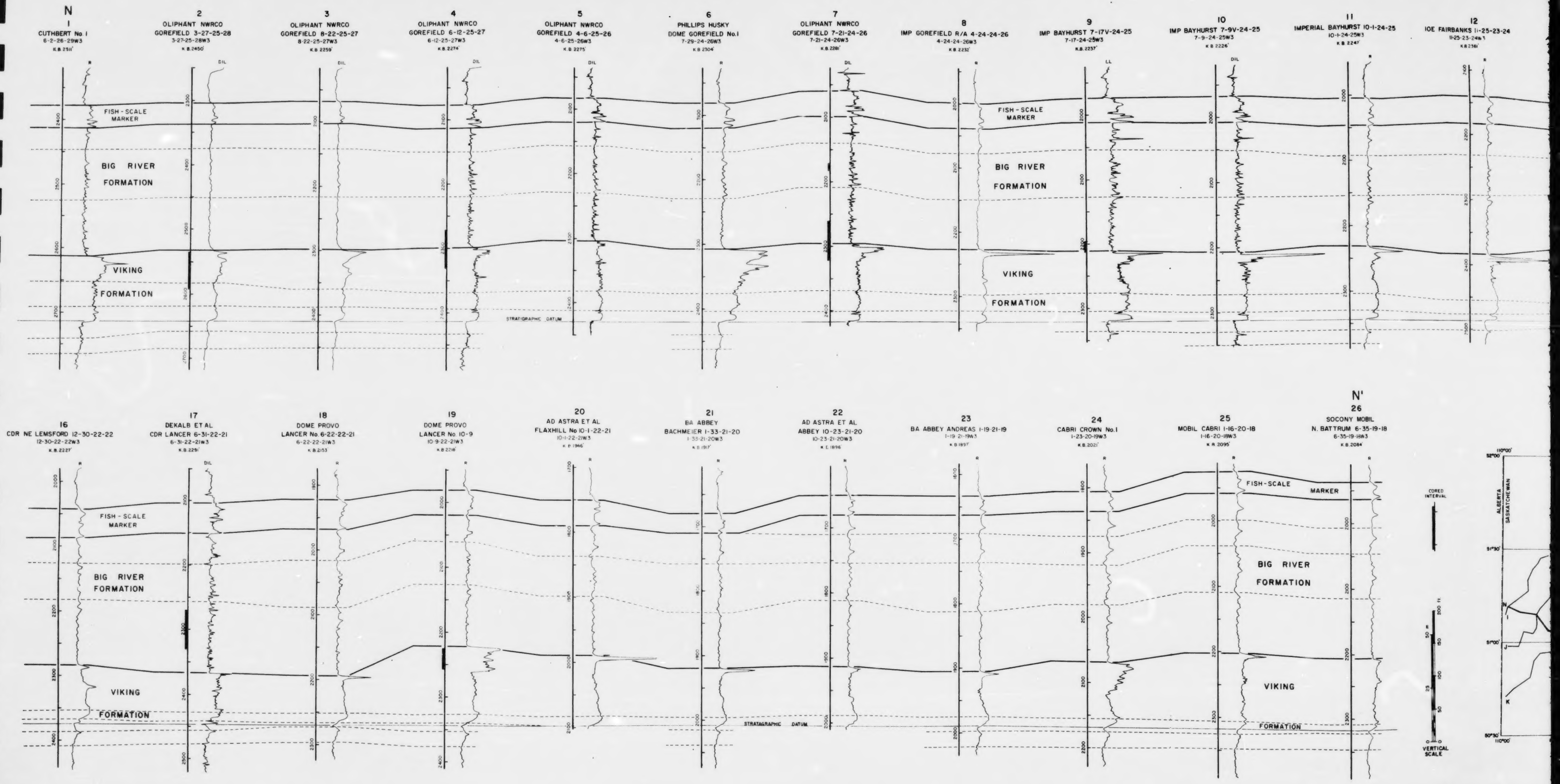

5
ONWARD 6-24
6-24-32-24W3
K B 2325
6
CANPET
SARCEE N EUREKA 11-9
11-9-32-23W3
K B 2326'
7
ALTAIR SARCEE
EUREKA 3-2-32-23
3-2-32-23W3
K B 2291'
8
IMPERIAL EUREKA
No. 11-35V-31-23
11-35-31-23W3
K B 2304'
9
ALTAIR ET AL COL
SMI 8-35-31-23
8-35-31-23W3
K B 2292'
10
IMP EUREKA COL
SMI 15-25V-31-23
15-25-31-23W3
K B 2298
11
IMP EUREKA COL
SMI 9-25V-31-23
9-25-31-23W3
K B 2293
12
ALTAIR ET AL COL
SMI 4-30-31-22
4-30-31-22W3
K B 2287
13
IMP HOPEDALE COL
SMI 5-19V-31-22
5-19-31-22W3
K B 2270
14
CANSO FINA
EUREKA 7-18-31-22
7-18-31-22W3
K B 2260
15
GER CALMANO
DODSLAND 13-8-31-22
13-8-31-22W3
K B 2257
16
HOUSTON HB GE
DODS 2-8-31-22
2-8-31-22W3
K B 2225
SE
R
LL
BIG RIVER FORMATION
FISH SCALE MARKER
VIKING FORMATION
BIG RIVER FORMATION
FISH SCALE MARKER
VIKING FM.
STRATIGRAPHIC DATUM
2000
2100
2200
2300
2400
M'
20
SARCEE GEOG AH
DODS 12-28-30-22
12-28-30-22W3
K B 2260
21
GEOG PRO ET AL
AH DODS 12-20-30-22
12-20-30-22W3
K B 2321
22
MURPHY KIYIU 12-16-30-22
12-16-30-22W3
K B 2323
23
MURPHY KIYIU 2-16-30-22
2-16-30-22W3
K B 2309
24
GORD-MARK AVON
HILLS 12-3-30-22
12-3-30-22W3
K B 2323
25
ZD HB PETRO DY
BEADLE 1-22-29-22
1-22-29-22W3
K B 2330
DIL
BIG RIVER FORMATION
FISH SCALE MARKER
VIKING FORMATION
CORED INTERVAL
VERTICAL SCALE
200 ft
150
100
50
0
50 m
25
0
ALBERTA
SASKATCHEWAN
110°00'
109°30'
109°00'
108°30'
108°00'
107°30'
52°00'
51°30'
51°00'
50°30'
KERROBERT
M
COLEVILLE
M'
KINDERSLEY
ROSETOWN
I'
J'
K'
L'
EATONIA
ESTON
ELROSE
N
I
J
PRELATE
K
L
CABRI
N'
LOCATION MAP
Mi 10 0 10 Mi
km 10 0 10 km

Figure 24 — Northwest-southeast stratigraphic cross-section M-M′ of Viking and Big River strata between the Stanolind Canso Superb No. 1 (Lsd 13-24-33-25W3) and ZDHB Petrody Beadle 1-22-29-22 (Lsd 1-22-29-22W3) wells.


N
1
CUTHBERT No. I
6-2-26-29W3
K.B. 2511'
2
OLIPHANT NWRCO
GOREFIELD 3-27-25-28
3-27-25-28W3
K.B. 2450'
3
OLIPHANT NWRCO
GOREFIELD 8-22-25-27
8-22-25-27W3
K.B. 2259'
4
OLIPHANT NWRCO
GOREFIELD 6-12-25-27
6-12-25-27W3
K.B. 2274'
5
OLIPHANT NWRCO
GOREFIELD 4-6-25-26
4-6-25-26W3
K.B. 2275'
6
PHILLIPS HUSKY
DOME GOREFIELD No.I
7-29-24-26W3
K.B. 2304'
7
OLIPHANT NWRCO
GOREFIELD 7-21-24-26
7-21-24-26W3
K.B. 2281'
8
IMP GOREFIELD R/A 4-24-24-26
4-24-24-26W3
K.B. 2232'
9
IMP BAYHURST 7-17V-24-25
7-17-24-25W3
K.B. 2237'
10
IMP BAYHURST 7-9V-24-25
7-9-24-25W3
K.B. 2226'
11
IMPERIAL BAYHURST 10-1-24-25
10-1-24-25W3
K.B. 2247'
12
IOE FAIRBANKS 11-25-23-24
11-25-23-24W3
K.B. 2361'
R
DIL
LL
FISH - SCALE
MARKER
BIG RIVER
FORMATION
VIKING
FORMATION
STRATIGRAPHIC DATUM
16
CDR NE LEMSFORD 12-30-22-22
12-30-22-22W3
K.B. 2227'
17
DEKALB ET AL
CDR LANCER 6-31-22-21
6-31-22-21W3
K.B. 2291'
18
DOME PROVO
LANCER No. 6-22-22-21
6-22-22-21W3
K.B. 2153'
19
DOME PROVO
LANCER No. 10-9
10-9-22-21W3
K.B. 2218'
20
AD ASTRA ET AL
FLAXHILL No 10-1-22-21
10-1-22-21W3
K.B. 1966'
21
BA ABBEY
BACHMEIER 1-33-21-20
1-33-21-20W3
K.B. 1917'
22
AD ASTRA ET AL
ABBEY 10-23-21-20
10-23-21-20W3
K.B. 1896'
23
BA ABBEY ANDREAS 1-19-21-19
1-19-21-19W3
K.B. 1997'
24
CABRI CROWN No.1
1-23-20-19W3
K.B. 2021'
N'
25
MOBIL CABRI 1-16-20-18
1-16-20-18W3
K.B. 2095'
26
SOCONY MOBIL
N. BATTRUM 6-35-19-18
6-35-19-18W3
K.B. 2084'
CORED
INTERVAL
VERTICAL
SCALE
0
50 m
25
200 ft
150
100
50
110°00'
52°00'
51°30'
51°00'
50°30'
ALBERTA
SASKATCHEWAN
N
I
J
K

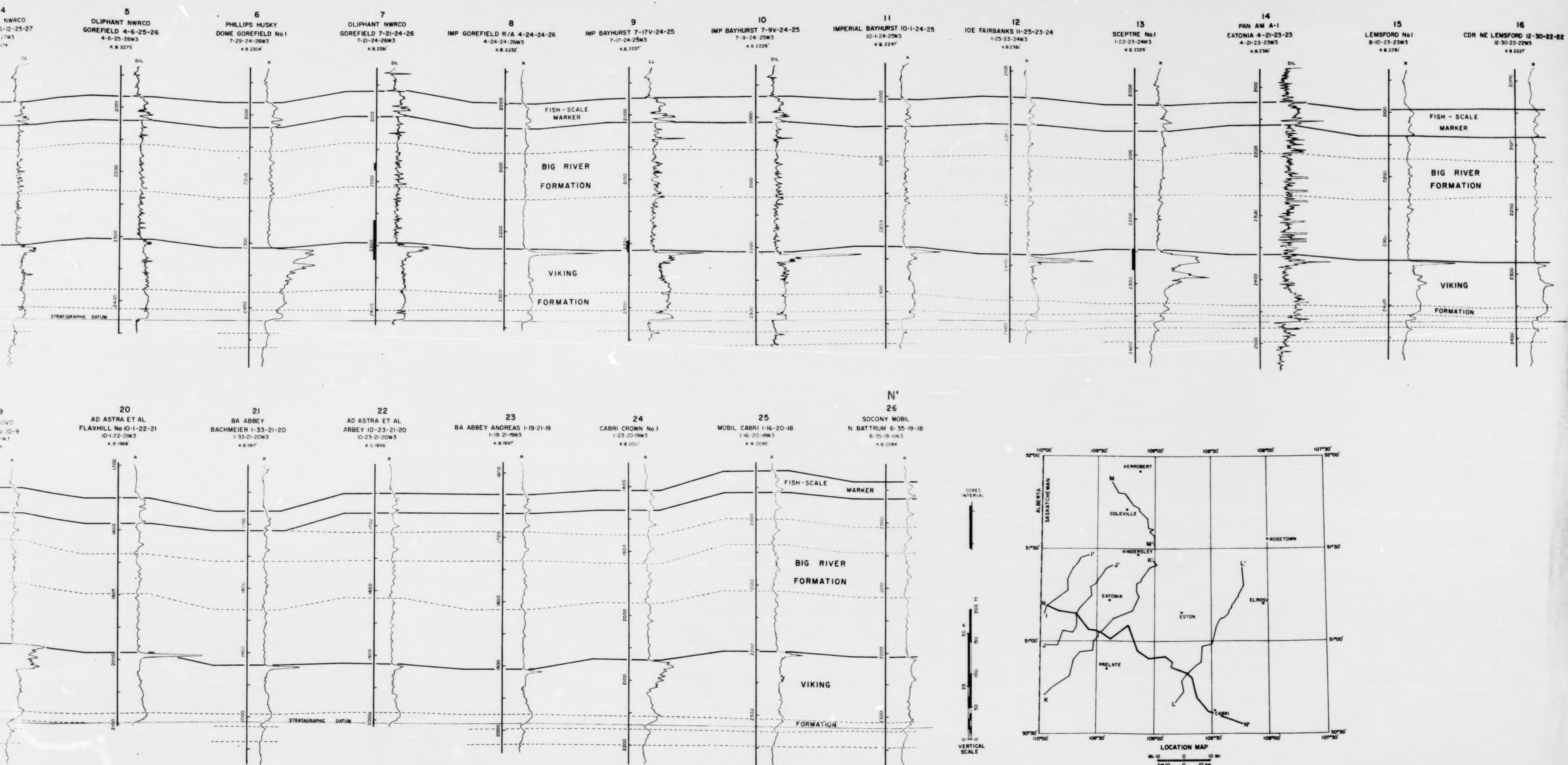

4
NWRCO
5
OLIPHANT NWRCO
GOREFIELD 4-6-25-26
4-6-25-26W3
K.B. 2275'
6
PHILLIPS HUSKY
DOME GOREFIELD No.1
7-29-24-26W3
K.B. 2304'
7
OLIPHANT NWRCO
GOREFIELD 7-21-24-26
7-21-24-26W3
K.B. 2291'
8
IMP GOREFIELD R/A 4-24-24-26
4-24-24-26W3
K.B. 2232'
9
IMP BAYHURST 7-17V-24-25
7-17-24-25W3
K.B. 2237'
10
IMP BAYHURST 7-9V-24-25
7-9-24-25W3
K.B. 2226'
11
IMPERIAL BAYHURST 10-1-24-25
10-1-24-25W3
K.B. 2247'
12
IOE FAIRBANKS 11-25-23-24
11-25-23-24W3
K.B. 2361'
13
SCEPTRE No.1
1-22-23-24W3
K.B. 2229'
14
PAN AM A-1
EATONIA 4-21-23-23
4-21-23-23W3
K.B. 2361'
15
LEMSFORD No.1
8-10-23-23W3
K.B. 2281'
16
CDR NE LEMSFORD 12-30-22-22
12-30-22-22W3
K.B. 2227'
DIL
R
LL
FISH - SCALE MARKER
BIG RIVER FORMATION
VIKING FORMATION
STRATIGRAPHIC DATUM
20
AD ASTRA ET AL
FLAXHILL No 10-1-22-21
10-1-22-21W3
K.B. 1966'
21
BA ABBEY
BACHMEIER 1-33-21-20
1-33-21-20W3
K.B. 1917'
22
AD ASTRA ET AL
ABBEY 10-23-21-20
10-23-21-20W3
K.B. 1896'
23
BA ABBEY ANDREAS 1-19-21-19
1-19-21-19W3
K.B. 1997'
24
CABRI CROWN No.1
1-23-20-19W3
K.B. 2021'
25
MOBIL CABRI 1-16-20-18
1-16-20-18W3
K.B. 2095'
N'
26
SOCONY MOBIL
N. BATTRUM 6-35-19-18
6-35-19-18W3
K.B. 2084'
FISH-SCALE MARKER
BIG RIVER FORMATION
VIKING FORMATION
STRATAGRAPHIC DATUM
CORED INTERVAL
200 ft
50 m
VERTICAL SCALE
ALBERTA
SASKATCHEWAN
KERROBERT
COLEVILLE
ROSETOWN
KINDERSLEY
EATONIA
ESTON
ELROSE
PRELATE
CABRI
M
M'
I
I'
J
J'
K
K'
L
L'
N
N'
110°00'
109°30'
109°00'
108°30'
108°00'
107°30'
52°00'
51°30'
51°00'
50°30'
LOCATION MAP
mi 10 0 10 mi
km 10 0 10 km

Figure 25 — Northwest-southeast stratigraphic cross-section N-N' of Viking and Big River strata between the Cuthbert No. 1 (Lsd 6-2-26-29W3) and Socony Mobil N Battrum 6-35-19-18 (Lsd 6-35-19-18W3) wells.

Typical core descriptions for the proximal-shelf facies are given in the discussion of Viking clinobeds below; the distal-shelf facies is exhibited in the core from the Sohio et al Arelee 12-9-38-11 well (Lsd 12-9-38-11W3) described as follows:

SOHIO ET AL ARELEE 12-9-38-11
Lsd 12-9-38-11W3 KB 551.4 m (1,809 ft)

Depth below KB in metres (feet)	
	VIKING FORMATION
488.3 - 489.8 (1,602 - 1,607)	Mudstone with siltstone intercalations: mudstone medium dark to dark grey, frequently silty, micaceous, finely laminated; siltstone medium grey, sandy, micaceous, as layers up to 8 mm thick with horizontal and gently inclined laminae; with fish remains.
489.8 - 491.6 (1,607 - 1,613)	Siltstone and very fine-grained sandstone: siltstone, sandstone medium grey, quartzose, micaceous, with scarce scattered coarser sand grains, granules and small pebbles (chert) becoming numerous for 5 cm at ca. 490 m, subordinate pyrite cement, partly pyritized fragments of plant debris, with numerous interconnected mudstone partings and thin continuous intercalations; with *Teichichnus, Chondrites.*
491.6 - 492.6 (1,613 - 1,616)	Mudstone with siltstone and very fine-grained sandstone intercalations: as 488.3 - 489.8 m but with increased sand content.
	JOLI FOU FORMATION
492.6 - 493.8 (1,616 - 1,620)	Mudstone with scarce siltstone and very fine-grained sandstone intercalations: lithologies as 488.3 - 489.8 m with slightly increased sand content.
493.8 - 496.8 (1,620 - 1,630)	Mudstone with siltstone and fine-grained sandstone intercalations: as 488.3 - 489.8 m, but with increased sand content as micaceous, slightly glauconitic layers up to 7 mm thick with horizontal and gently inclined laminae, sharp contacts; with fish remains.
496.8 - 498 (1,630 - 1,634)	No core.
498 - 501.1 (1,634 - 1,644)	Mudstone with siltstone and fine-grained sandstone intercalations: as 493.8 - 496.8 m; very light grey bentonitic mudstone in two 1 cm layers; 8 cm ferruginous silty mudstone near base. (Recovery ca. 1.2 m).

The Viking Chert is the basal reservoir unit of the Viking Formation in the Smiley-Dewar, North Hoosier and North Eureka production locales of west-central Saskatchewan. The unit is made up of conglomerate, interbedded with pebbly mudstone and pebbly, fine to coarse-grained sandstone. Crude, irregular layering, commonly discontinuous in places is displayed and chert is the principal detrital component of the coarse-sand through pebble grades.

Viking Chert also occurs as irregular lenses at the base of the Viking Formation in the Dodsland-Hoosier production trend of west-central Saskatchewan and other fields of the same trend, notably at the Avon Hill, Milton and Whiteside fields. The thickness of the Chert is generally less than 1.4 m.

The basal contact of the Chert is sharp and disconformable, the upper contact gradational. The chert-pebble conglomerates for the most part are basal to a series of upward coarsening clinobeds bounded by bentonite layers. However, insofar as the Smiley-Dewar and North Eureka Viking Cherts are coincident with deeply incised valleys at the sub-Mesozoic unconformity, control of the distribution of the former by the latter seems probable.

Viking Correlation Problems

The gradational relationships between lithologic associations within the Viking Formation and between Viking lithologies and enveloping argillaceous deposits, greatly complicate attempts to correlate sandstone bodies from one well to another. Contacts with the Big River and Joli Fou shales and mudstones are relatively sharp in the shoreline-nearshore deposits in the southwest of the study area. However, in the proximal-shelf shaly sandstones of the Dodsland-Hoosier production district, the upper contact of the Viking Formation is difficult to recognize consistently. Practical usage has to a large extent taken the step of isolating the sandy and conglomeratic part of the unit by arbitrary cut off under the designation "Viking Sand". The present account follows the approach, taken by Jones (1961a, 1961b), in attempting to correlate siltstones and shaly, fine-grained sandstones, which give a characteristic resistivity response at the top of the unit. North of the Dodsland-Hoosier area, the Viking Formation of this account differs very little from the "Viking Sand", as a consequence of the reduced thickness and decrease in grain size northeastward.

Viking Clinobeds

The existence of clinobeds in the Viking Formation of the Dodsland-Hoosier production locale of west-central Saskatchewan was first demonstrated by Reasoner and Hunt (1954a). A system of members, alphabetically designated "K", "Upper L", "M", "N" and "O" was worked out by Evans (1970) on the basis of detailed electric-log correlation.

The Merrington Clinobed is equivalent to the "K" member of Evans (1970). The name is taken from the Phillips Husky Merrington No. 1 well (Lsd 14-30-29-23W3), which penetrated the maximum thickness. The type section is in the GEOG et al AH Dods 12-20-30-22 well (Lsd 12-20-30-22W3) from 723.6 to 729.8 m (2374 to 2394.5 ft), and is described in Simpson 1979, p. 50.

The Merrington Clinobed is a shaly, fine-grained, slightly glauconitic sandstone with subordinate conglomerate and pebbly sandstone, and is largely made up of alternating, thin layers of sandstone and upward decreasing non-calcareous mudstone. Pebbly, coarse-grained sandstone occurs as an irregular layer up to a metre thick above a basal bentonitic mudstone. The uppermost metre consists of mudstone with interbedded siltstone and fine-grained sandstone.

The maximum thickness of the unit is 10.7 m and it forms a broad belt, trending east-west across the central and southern parts of the production area and in the north, west-southwest.

The Merrington Clinobed overlaps the St. Eloi and Crystal clinobeds and the equivalent sandy shales. Contacts with the underlying clinobeds are sharp. The unit thins markedly to the north and passes into sandy shale. It grades upward into shales of the overlying Big River Formation.

The St. Eloi Clinobed is equivalent to the "Upper L" member of Evans (1970). The name is taken from the Phillips St. Eloi A7-10 well (Lsd 7-10-30-23W3), which penetrated the maximum thickness. The type section is in the Murphy Kiyiu 4-12-30-22 well (Lsd 4-12-30-22W3) from 709.3 to 713.2 m (2327 to 2340 ft). See Simpson, 1970.

The St. Eloi Clinobed consists of shaly fine-grained, slightly glauconitic sandstone with minor conglomerate and pebbly sandstone. Characteristically sandstone beds, a few centimetres thick, alternate with mudstone layers of similar thickness. The proportion of interbedded mudstone decreases upward but is accompanied by an increase in the degree of bioturbation. Coarse-grained sandstone and pebbly sandstone occur sporadically at the base of the unit.

The unit is up to 4.9 m thick and forms a belt, which extends westwards across the south of the production area; the northern edge of the unit trends west-southwesterly and the southern perimeter westerly.

The St. Eloi Clinobed onlaps the Crystal Clinobed in the north and oversteps the Joli Fou Formation farther south. It is overlapped by the Merrington Clinobed on a sharp contact defined by the base of a thin bentonitic mudstone. In the northern part of the production area the St. Eloi passes into sandy shale.

The Crystal Clinobed is the "Lower L" member of Evans (1970). The name is taken from the Royalite Crystal No. 1 well (Lsd 10-33-30-24W3), which penetrates the maximum thickness. The type section is in the Imp Eureka Col Smi 9-25V-31-23 well (Lsd 9-25-31-23W3) from 701.3 to 704.4 m (2,301 to 2,311 ft). See Simpson, 1979, p. 65.

The unit comprises shaly, fine to coarse-grained sandstone and subordinate conglomerate and pebbly sandstone. The shaly sandstone consists of largely fine-grained sandstone beds, a few centimetres thick, regularly alternating with non-calcareous mudstones of similar thickness. The proportion of interbedded mudstone decreases upward and is accompanied by an increase in bioturbation. The sandstones are glauconitic in places. Conglomerates and pebbly sandstones occur locally at the base of the unit.

The Crystal Clinobed forms a west-southwesterly belt across the central part of the production locale and is a maximum 11 m thick. It onlaps the Hoosier Clinobed in the north and is locally conglomeratic where it oversteps the Joli Fou Formation farther south. The Crystal Clinobed is overlapped by both the St. Eloi and Merrington Clinobeds. The contact with the St. Eloi shaly sandstones is gradational, but that with the Merrington Clinobed is sharply defined by the base of a prominent bentonitic mudstone. In the northern part of the production area, the Crystal Clinobed passes into sandy shale.

The Hoosier Clinobed is the "M" member of Evans (1970). The name is taken from the Hoosier Unit 5-8 well (Lsd 5-8-31-26W3) which penetrates the maximum thickness. The type section is in the Canpet Highwood Eureka 10-36 well (Lsd 10-36-31-23W3) from 686.3 to 690.2 m (2,251.5 to 2,264.5 ft). See Simpson, 1979, p. 66.

The lithologic associations within the Hoosier Clinobed are shaly, fine to coarse-grained sandstone and subordinate conglomerate and pebbly sandstone. The shaly sandstone is a largely fine-grained, coarsening-upward sequence, in which bioturbated sandstone with numerous shale partings is replaced downwards by regularly alternating, thin beds of sandstone and shale and at the base by 0.5 m of bentonitic mudstone. Locally conglomerates and pebbly sandstones form a basal deposit.

The unit attains a maximum thickness of 8.2 m in its west-southwest trending belt across the central part of the production locale. The Hoosier Clinobed onlaps the Smiley Clinobed in the north, oversteps the Joli Fou Formation farther south and is succeeded by the argillaceous part of the Crystal Clinobed. Locally this contact is at the base of a bentonitic mudstone.

The Smiley Clinobed is equivalent to the "N" and "O" members of Evans (1970). The name is taken from the Sturgeon Smiley No. 1 well (Lsd 13-13-32-26W3) which penetrates the maximum thickness of the "N" member. The type section is in the Canpet Sarcee N Eureka 11-9 well (Lsd 11-9-32-23W3) from 731.7 to 737.3 m (2,400.5 to 2,419 ft) as described by Simpson, 1979, p. 68.

The Smiley Clinobed is made up of shaly, fine to coarse-grained sandstone and subordinate conglomerate and pebbly sandstone. The shaly sandstone consists of largely fine-grained sandstone beds a few centimetres thick, with non-calcareous mudstones of similar thickness. A generalized upward decrease in the proportion of mudstone and increase in bioturbation is apparent. Locally, basal conglomerates and pebbly sandstones occur.

The unit attains a maximum thickness of 8.5 m near the Fourth Meridian and trends west-southwesterly in the northern part of the production locale.

It rests disconformably on the Joli Fou shales and makes sharp contact with overlying sandy shales, equivalent to the Crystal and possibly Hoosier Clinobeds, which rest upon it in the north. It is overlain by the Hoosier Clinobed farther south. The upper contact of the Smiley Clinobed is in both cases at the sharp base of a bentonite bed.

Flotten Lake Sand

The type section is in the D.N.R. Flotten Lake No. 2 well (Lsd 4-10-65-17W3), from 180.4 to 199.3 m (592 to 654 ft). Since no geophysical well logs were run in the type well, the electric-log section from 287.1 to 303.2 m (942 to 995 ft) in the Clark Flotten Lake 4-22-66-17 well (Lsd 4-22-66-17W3) is used as a reference.

DNR FLOTTEN LAKE NO. 2
Lsd 4-10-65-17W3 GL 488 m (1,601 ft)

Depth below GL in metres (feet)	**BIG RIVER FORMATION**
	Big River mudstone
163.7 - ca. 180.4 (537 - ca. 592)	Alternations of mudstone and siltstone/very fine-grained sandstone: mudstone medium dark to dark grey, generally silty, micaceous, finely laminated; siltstone, sandstone light olive grey, quartzose, micaceous, horizontally laminated with some upward grading; mud content apparently increases toward base of interval; high kaolinite content at 171.3 m (ca. 15 cm), 172.8 m (ca. 23 cm).
	Flotten Lake Sand
ca. 180.4 - 189.3 (ca. 592 - 621)	Sand: yellowish grey at top to light grey near base, unconsolidated, predominantly fine-grained with medium and coarse grains near top and at base; almost entirely made up of sub-angular to rounded quartz grains; fish remains common particularly 181.1-186.2 m.
189.3 - 199.3 (621 - 654)	Alternations of fine-grained sandstone/siltstone and mudstone: sandstone, siltstone generally light grey to yellowish grey, light olive grey near base, induration poor to medium friable; quartz-rich; 20 cm fine-grained glauconitic, micaceous, horizontally laminated sandstone near base; mudstone medium dark to dark grey, silty laminated.
	JOLI FOU FORMATION
199.3 - 238 (654 - 781)	Mudstone with siltstone and fine-grained sandstone intercalations: mudstone, medium dark to dark grey, mostly silty, micaceous, very finely laminated; siltstone, sandstone light grey to yellowish grey, quartzose, micaceous, slightly glauconitic, as flattened lenses and continuous layers up to 25 mm thick with horizontal and gently inclined laminae, sharp contacts with sole markings; with fish remains, pelecypod debris near base.

Correlation between type and reference sections is made in Fig. 26; correlation is also made with the cored section of Flotten Lake Sand, recovered from the St. Walburg No. 1 well (Lsd 14-31-55-21W3). See Simpson, 1979, p. 46.

The Flotten Lake Sand is a variably consolidated, well washed, fine to medium-grained sand and sandstone and shaly, fine-grained sandstone. The well washed sands and sandstones are quartz-rich and cross-laminated. The shaly sandstones and siltstones form irregular, thin, graded layers, interbedded with mudstones of similar thickness.

The thickness in the type section is 18.9 m. South of the town of Meadow Lake, the maximum value is 21.3 m. The Flotten Lake Sand is restricted to the western part of a prominent structural platform in west-central Saskatchewan and adjacent east-central Alberta, its southern limit approximately delineated by the valley of the North Saskatchewan River (Fig. 27). The unit is a relatively coarse-grained wedge, which undergoes a southwesterly grain-size diminution and thickness decrease.

The Flotten Lake Sand rests conformably on shales of the Joli Fou Formation and is itself conformably overlain by shales of the Big River Formation. It is the approximate lithostratigraphic equivalent of the northeastward-thinning Viking Formation of southern Saskatchewan and adjacent areas. Southeast of Meadow Lake, the Big River shale between the Flotten Lake Sand and the St. Walburg Sandstone pinches out and the two relatively coarse-grained units form a single sandy body.

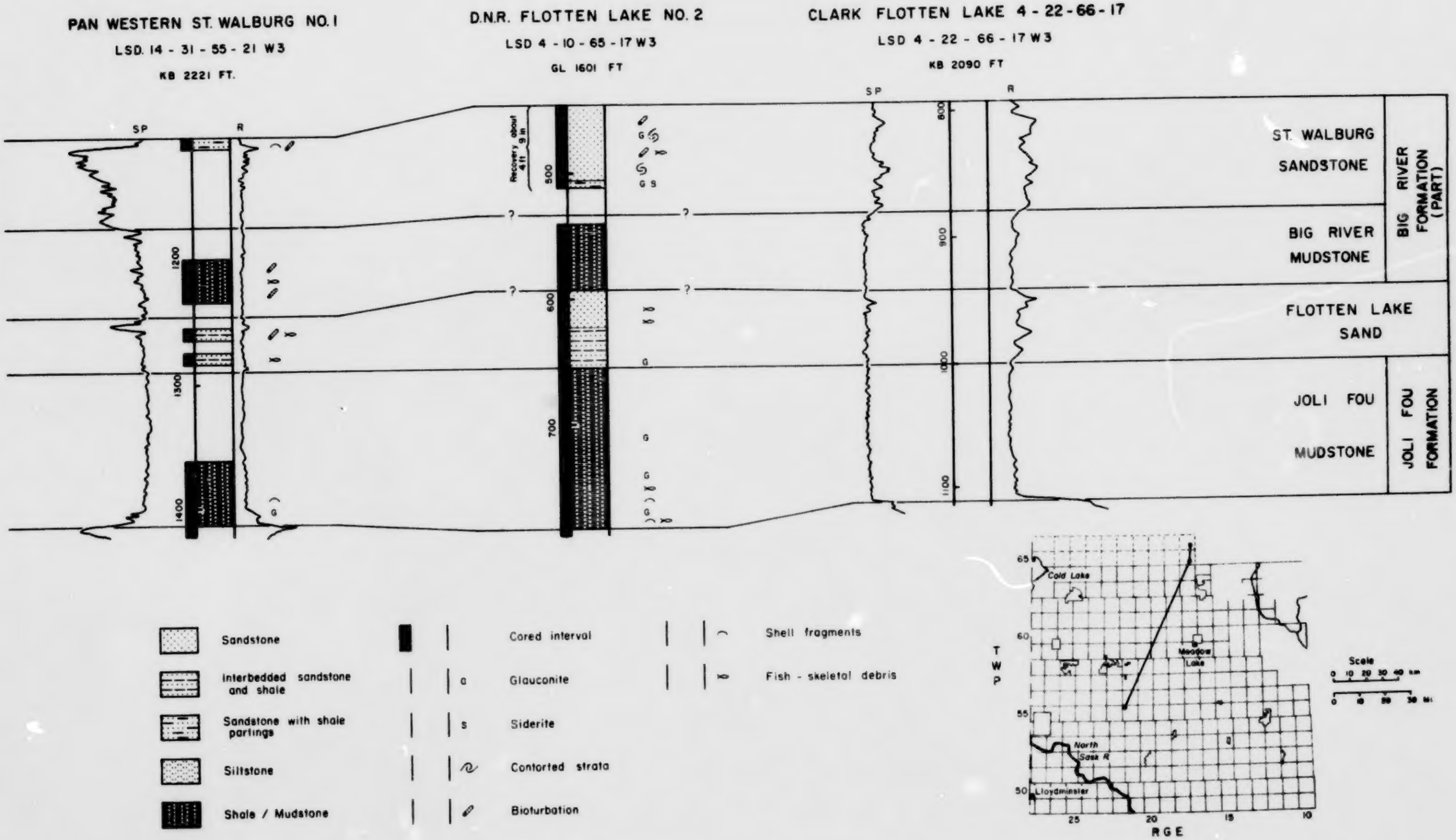

PAN WESTERN ST. WALBURG NO. 1
LSD. 14 - 31 - 55 - 21 W3
KB 2221 FT.
D.N.R. FLOTTEN LAKE NO. 2
LSD 4 - 10 - 65 - 17 W3
GL 1601 FT
CLARK FLOTTEN LAKE 4 - 22 - 66 - 17
LSD 4 - 22 - 66 - 17 W3
KB 2090 FT
SP
R
1200
1300
1400
Recovery about 4 ft 9 in
500
600
700
800
900
1000
1100
?
G
S
ST. WALBURG SANDSTONE
BIG RIVER MUDSTONE
BIG RIVER FORMATION (PART)
FLOTTEN LAKE SAND
JOLI FOU MUDSTONE
JOLI FOU FORMATION
Sandstone
Interbedded sandstone and shale
Sandstone with shale partings
Siltstone
Shale / Mudstone
Cored interval
Glauconite
Siderite
Contorted strata
Bioturbation
Shell fragments
Fish - skeletal debris
Cold Lake
Meadow Lake
North Sask R.
Lloydminster
TWP
65
60
55
50
RGE
25
20
15
10
Scale
0 10 20 30 40 km
0 10 20 30 mi

Figure 26 — Correlations between type and reference sections for the Flotten Lake Sand in west-central Saskatchewan.

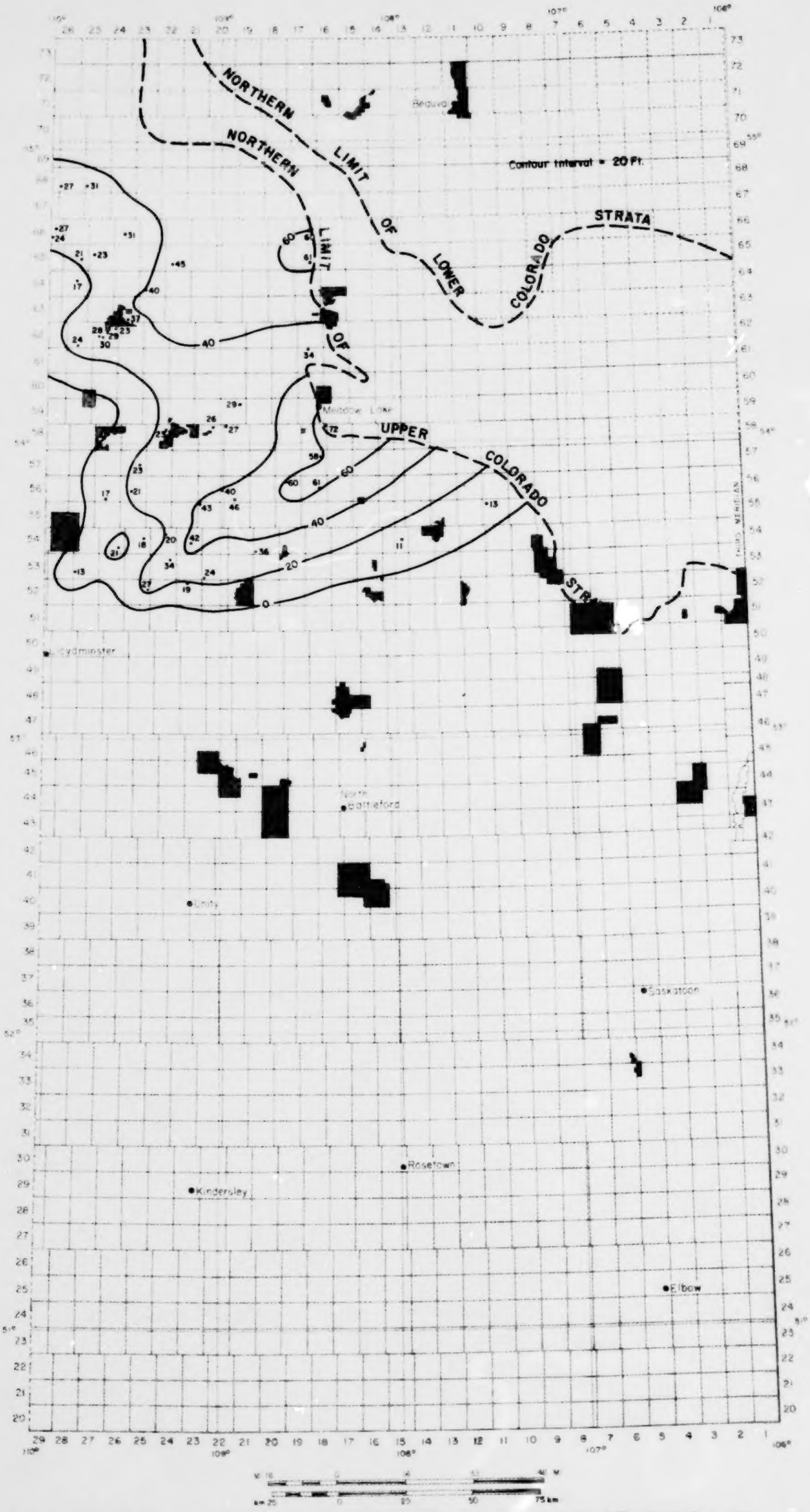

NORTHERN LIMIT OF LOWER COLORADO STRATA
NORTHERN LIMIT OF UPPER COLORADO STRATA
Contour interval = 20 Ft.
Beauval
Meadow Lake
Lloydminster
North Battleford
Unity
Saskatoon
Rosetown
Kindersley
Elbow
THIRD MERIDIAN
0
20
40
60
km
M

Figure 27 — Isopach map of the Flotten Lake Sand in west-central Saskatchewan.

Joli Fou Formation

The type section is located in Alberta along the Athabasca River, between Pelican Rapids and 5 kilometres (8 miles) downstream from Joli Fou Rapids (Wickenden, 1949). The dominant lithology is dark grey, non-calcareous shale, with minor interbedded fine and medium-grained sandstone. The sandstone occurs as lenses, commonly a few millimetres thick, and as graded layers, up to several centimetres in thickness, composed of horizontal or gently inclined laminae. Bioturbated, shaly sandstones form scarce layers, several centimetres thick. In the upper part of the unit, the sandstone is quartzose and micaceous, but near the base, glauconitic sandstone and quartz arenite are common. Subordinate lithologies include bentonite, pelecypod coquinas, nodular phosphorite, and concretionary layers of calcite, siderite and pyrite. In central Saskatchewan, the formation consists of interbedded glauconitic sandstone and non-calcareous mudstone of the Spinney Hill Sandstone, overlain by northward-thinning shales. The Joli Fou Formation includes the interbedded shaly sandstone, siltstone and mudstone of the Cessford Sand in southeastern Alberta.

The Formation is about 33.5 m thick in the Athabasca River exposures; it thins to about 10.7 m south of the Lesser Slave Lake area and 16.8 m in the Redwater area. The sequence pinches out in the Rocky Mountain foothills of southern Alberta, where it is replaced by the lowermost sandstones of the Bow Island Formation. The Joli Fou Formation attains a thickness of about 61 m in south-central Saskatchewan. The unit is widespread in the subsurface of the western Canada sedimentary basin.

The Joli Fou Formation is the basal unit of the Colorado Group. In northeastern Alberta, it rests on the Grand Rapids Formation of the Mannville Group and is overlain by the Pelican Formation. In southern Alberta and southern Saskatchewan, it rests disconformably on the Mannville Formation, and is overlain by sandstones of the Bow Island-Viking succession. The Viking-Joli Fou contact is a disconformity in west-central Saskatchewan. Where the Viking Formation is absent in parts of southern Saskatchewan, the Joli Fou and Big River Formations form a sequence of undifferentiated Lower Colorado shale. In central Saskatchewan the Joli Fou is in sharp contact with the overlying Flotten Lake Sand. In southern Manitoba the Joli Fou corresponds to the lower part of the Lower Ashville and in north-central Montana and North Dakota is equivalent to the Skull Creek Shale.

Spinney Hill Sandstone

The name Spinney Hill Sandstone was first applied by F. H. Edmunds to the glauconitic sandstone unit, occupying the lower part of the Joli Fou Formation in the Spinney Hill No. 1 well (Lsd 16-24-40-14W3), drilled near Spinney Hill, Saskatchewan. A new type well, designated by Edwards (1960), is the Liberal Canada Southern New Devon Skyline No. 2 well (Lsd 3-6-37-16W3).

SPINNEY HILL NO. 1
Lsd 16-24-40-14W3 KB 632.2 m (2,074 ft)

Depth below KB in metres (feet)	
	JOLI FOU FORMATION
	Joli Fou mudstone
532.8 - 533.7 (1,748 - 1,751)	Mudstone: dark grey, laminated where silty, with scarce intercalations of siltstone, fine-grained sandstone.
533.7 - 548 (1,751 - 1,798)	No core.
	Spinney Hill Sandstone
548 - 562.4 (1,798 - 1,845)	Alternation of mudstone and fine-grained sandstone: mudstone dark grey, laminated and micaceous where silty; sandstone light olive grey to greyish green, predominantly fine-grained, induration moderate to poor, cross-laminated, quartzose, micaceous, slightly glauconitic to glauconite-rich; lowermost 2.4 m contain fine to coarse-grained sandstones, well indurated, with calcite cement, (?) phosphatic bodies, fish remains, as well as fine-grained quartzose sandstone with numerous interconnected mudstone partings.

The partial Spinney Hill sections cored in two additional wells are taken as being representative of proximal (northern) and distal (southern) facies respectively: the DNR Big River No. 5 well (Lsd 2-22-58-9W3) and the Ceepee Daniels 6-29 well (Lsd 6-29-31-19W3).

DNR BIG RIVER NO. 5

Lsd 2-22-58-9W3 KB ca. 499.9 m (1,640 ft)

Spinney Hill Sandstone

Depth below KB in metres (feet)	
121.9 - 131.4 (400 - 431)	Intercalated mudstone and fine-grained sandstone: mudstone dark grey, silty in places, micaceous, frequently laminated; sandstone generally light olive grey to bright light olive, quartzose, micaceous, slightly to very glauconitic, with kaolinite, accessory pyrite; in basal 30 cm, sandstone light grey to light greenish grey, of good induration, predominantly fine-grained but with coarser sand grains, granules, scarce pebbles concentrated in groups of laminae, quartz-rich with abundant calcite cement, in horizontal and gently inclined laminae.

CEEPEE DANIELS 6 - 29

Lsd 6-29-31-19/W3 KB 685.5 m (2,249 ft)

JOLI FOU FORMATION

Joli Fou mudstone

Depth below KB in metres (feet)	
688.8 - 692.8 (2,260 - 2,273)	Mudstone with siltstone and fine-grained sandstone intercalations: mudstone medium dark to dark grey, micaceous and finely laminated where silty, with fish remains; siltstone, sandstone light olive grey, quartzose, micaceous, glauconitic in flattened lenses and composite layers several centimetres thick; at 689.2 m, 10 cm of fine-grained sandstone with mudstone partings, abundant fish remains, pebbles of phosphatic material and glauconitic sandstone, maximum clast size 33mm; nodular pyrite concretions; burrowed with indeterminate horizontal sand-filled tubular forms, *Chondrites*.

Spinney Hill Sandstone

692.8 - 693.4 (2,273 - 2,275)	Sandstone: with subordinate mudstone intercalations; dusky yellow green to light olive grey, 25 mm coarse to medium-grained, remainder fine-grained; quartz-rich especially at base, glauconitic, micaceous; calcite cement where coarse, mudstone dark grey, micaceous and finely laminated where silty; interval comprises basal coarse-grained, cross-laminated sandstone with erosional base (5 cm), fine-grained sandstone with trough cross-laminae and thin continuous mudstone intercalations (75 mm), bioturbated and mechanically disrupted composite sandstone layers with erosional interfaces and flaser layering (30 cm), alternation of mudstone and sandstone (about 15 cm); with fish remains and pelecypod debris; burrowed with *Chondrites*, indeterminate sand -filled tubular forms.
693.4 - 693.9 (2,275 - 2,276.5)	Mudstone with siltstone and scarce fine-grained sandstone intercalations: mudstone dark grey, micaceous and finely laminated where silty, with fish remains; siltstone, sandstone quartzose, glauconitic, micaceous, in flattened lenses, tubular burrow infillings and scarce continuous layers up to 8 mm thick; burrowed, with *Chondrites*, sand-filled tubular forms.
693.9 - 694.8 (2,276.5 - 2,279.5)	Sandstone: as 692.8 - 693.4 m; bioturbated part 76 cm thick.

694.8 - 694.9 (2,279.5 - 2,280)	Mudstone with siltstone and scarce fine-grained sandstone intercalations: as 693.4 - 693.9 m.
694.9 - 695.1 (2,280 - 2,280.5)	Sandstone: as 692.8 - 693.4 m.
695.1 - 695.4 (2,280.5 - 2,281.5)	Mudstone with siltstone and scarce fine-grained sandstone intercalations: as 693.4 - 693.9 m.
695.4 - 696.6 (2,281.5 - 2,285.5)	Sandstone: as 692.8 - 693.4 m.
696.6 - 696.8 (2,285.5 - 2,286)	Mudstone with siltstone and scarce fine-grained sandstone intercalations: as 693.4 - 693.9 m.
696.8 - 697.1 (2,286 - 2,287)	Sandstone: as 692.8 - 693.4 m.
697.1 - 698.3 (2,287 - 2,291)	Mudstone with siltstone and scarce fine-grained sandstone intercalations: as 693.4 - 693.9 m.
698.3 - 699.2 (2,291 - 2,294)	Sandstone: as 692.8 - 693.4 m; 46 cm from base, sequence of internal structures repeated, beginning with cross-laminated glauconitic sandstone with *Teichichnus* and *Chondrites*.
699.2 - 699.4 (2,294 - 2,294.5)	Mudstone with siltstone and scarce fine-grained sandstone intercalations: as 693.4 - 693.9 m.
699.4 - 699.8 (2,294.5 - 2,296)	Sandstone: as 692.8 - 693.4 m; 15 cm coarse-grained calcareous sandstone rich in shell debris at base.
699.8 - 700 (2,296 - 2,296.5)	Mudstone with siltstone and scarce fine-grained sandstone intercalations: as 693.4 - 693.9 m.
700 - 700.6 (2,296.5 - 2,298.5)	Sandstone: as 692.8 - 693.4 m, but with medium-grained calcareous glauconitic sandstone repeated throughout interval.
700.6 - 701.3 (2,298.5 - 2,301)	Mudstone with siltstone and scarce fine-grained sandstone intercalations: as 693.4 - 693.9 m.
701.3 - 701.5 (2,301 - 2,301.5)	Sandstone: as 692.8 - 693.4 m, with 25 mm graded coarse to fine-grained sandstone at base.
701.5 - 702.1 (2,301.5 - 2,303.5)	Mudstone with siltstone and scarce fine-grained sandstone intercalations: as 693.4 - 693.9 m.
702.1 - 703 (2,303.5 - 2,306.5)	Sandstone incorporating conglomeratic layer: as 692.8 - 693.4 m; pebbles of coarse-grained calcareous sandstone, fine-grained cross-laminated sandstone, one clast with pelecypod valve impression, pelecypod and scaphopod debris present, calcite and pyrite cements, maximum clast length 84 mm; sandstone oil-stained in places.
703 - 703.6 (2,306.5 - 2,308.5)	Mudstone with siltstone and scarce fine-grained sandstone intercalations: as 693.4 - 693.9 m.
703.6 - 704.1 (2,308.5 - 2,310)	Sandstone: as 692.8 - 693.4 m.

Type and reference sections for the unit are correlated in Fig. 28.

The Spinney Hill is a greyish green and dusky yellowish green, very fine to coarse-grained, glauconitic sandstone interbedded with dark grey, non-calcareous shale and mudstone. It typically comprises repetitive, fining-upward sequences, each several metres thick and composed of cross-laminated sandstone with minor, intercalated shale, replaced upwards by regular alternations of sandstone and shale. In central Saskatchewan, the Spinney Hill includes only minor amounts of interbedded shale but the proportion of shale increases progressively southward. Bioturbated, shaly, glauconitic sandstone in layers up to a few decimetres thick, scarce, intraformational conglomerates and local concentrations of reworked, relict pebbles of nodular phosphorite also occur. Other subordinate lithologies include pelecypod coquinas and concretionary layers of siderite and pyrite.

The Spinney Hill Sandstone forms a prominent tongue, 60 km wide, extending southwards from the southwest of the Prince Albert National Park, to the west of and parallel to the South Saskatchewan River, and shaling out north of Swift Current (Fig. 29). The unit ranges in thickness from about 12.2 to 36.6 m, and averages 18.3 m.

In central Saskatchewan the Spinney Hill subcrops beneath a drift cover of variable thickness. Farther south the contact with overlying and flanking Joli Fou shales and mudstones is gradational but disconformable on the Mannville Group.

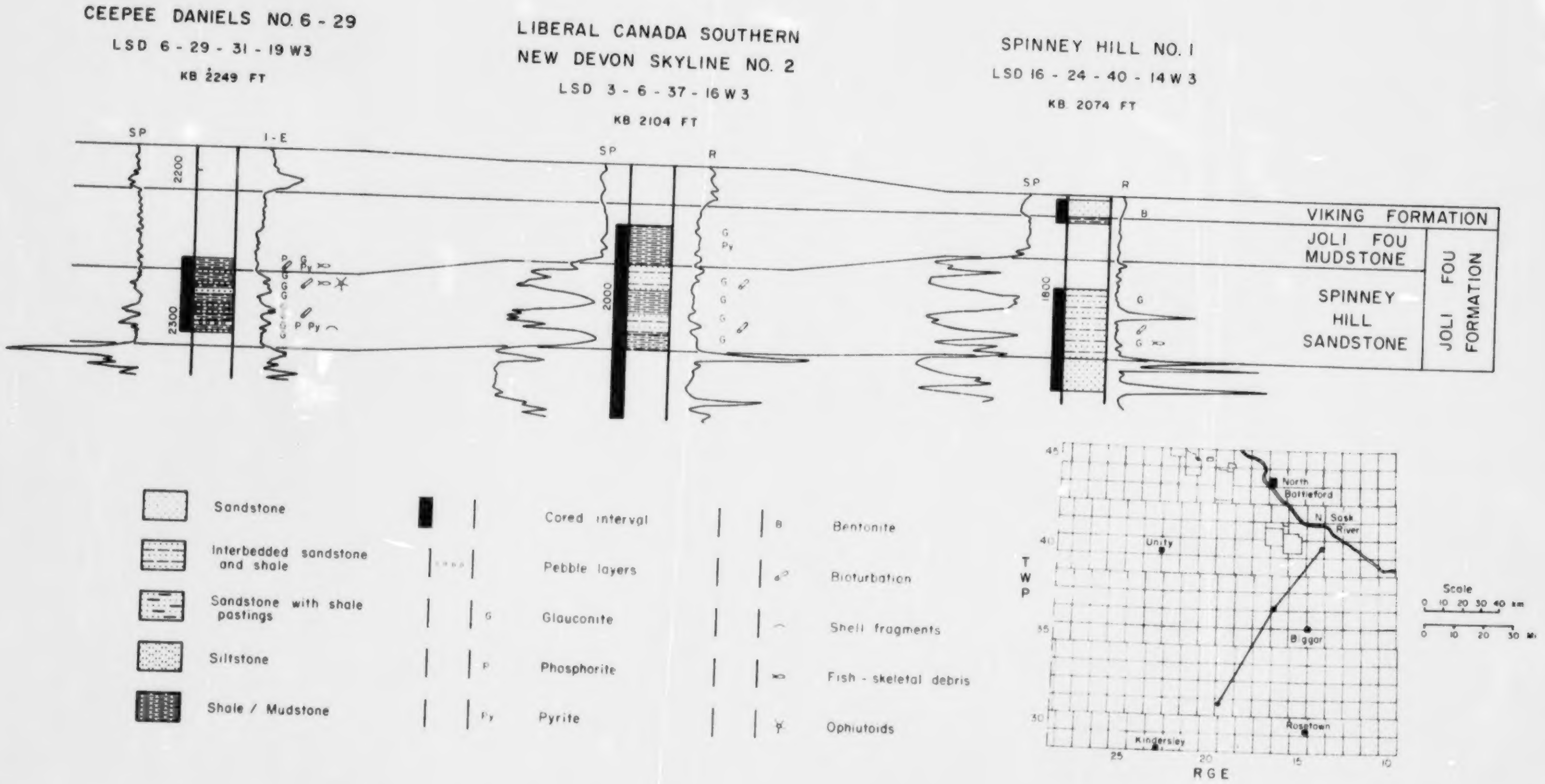

CEEPEE DANIELS NO. 6 - 29
LSD 6 - 29 - 31 - 19 W3
KB 2249 FT
LIBERAL CANADA SOUTHERN
NEW DEVON SKYLINE NO. 2
LSD 3 - 6 - 37 - 16 W 3
KB 2104 FT
SPINNEY HILL NO. 1
LSD 16 - 24 - 40 - 14 W 3
KB 2074 FT
SP
I - E
R
2200
2300
2000
1800
G
Py
P
B
VIKING FORMATION
JOLI FOU MUDSTONE
SPINNEY HILL SANDSTONE
JOLI FOU FORMATION
Sandstone
Interbedded sandstone and shale
Sandstone with shale pastings
Siltstone
Shale / Mudstone
Cored interval
Pebble layers
Glauconite
Phosphorite
Pyrite
Bentonite
Bioturbation
Shell fragments
Fish - skeletal debris
Ophiutoids
North Battleford
N. Sask River
Unity
Biggar
Kindersley
Rosetown
TWP
45
40
35
30
RGE
25
20
15
10
Scale
0 10 20 30 40 km
0 10 20 30 Mi

Figure 28 — Correlations between type and reference sections for the Spinney Hill Sandstone in west-central Saskatchewan.

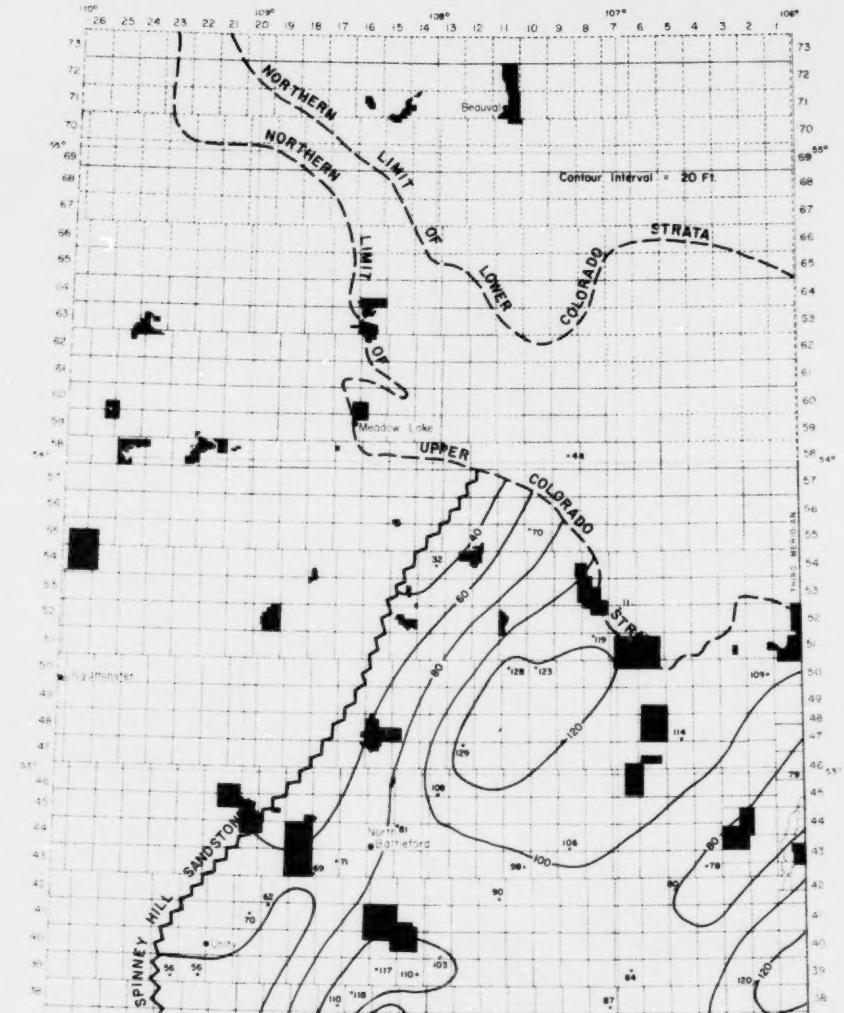

NORTHERN LIMIT OF LOWER COLORADO STRATA
NORTHERN LIMIT OF UPPER COLORADO STRATA
WESTERN LIMIT OF SPINNEY HILL SANDSTONE
Contour Interval = 20 Ft.
Beauval
Meadow Lake
Lloydminster
North Battleford
Unity
Saskatoon
Kindersley
Rosetown
Elbow
THIRD MERIDIAN
110°
109°
108°
107°
106°
55°
54°
53°
52°
51°
40
60
80
100
120

Figure 29 — Isopach map of the Spinney Hill Sandstone in west-central Saskatchewan.

Lithology

Sandstones and Siltstones

Description of cores include use of the rock colour chart compiled by Goddard *et al.* (1951) and their hue-lightness-chroma designation is employed in the present account.

Flaky and blocky, mostly non-calcareous, medium dark grey (N 4) and dark grey (N 3) mudstones make up a major proportion of the Big River and Joli Fou Formations with greyish black (N 2) mudstones of generally better fissility largely restricted to the uppermost Big River and the basal part of the Joli Fou. The principal sandy units are green beds (Spinney Hill), restricted to the lower half of the Joli Fou in the east of the area, and drab beds, belonging to the regressive Viking wedge of the southwest and equivalent lenticular bodies (St. Walburg and Flotten Lake) in the north.

In the green sediments, hues 10 Y, 5 GY and 10 GY with chroma categories 2 and 4 predominate, with lightness in the range 4 to 7, whereas in the drab siltstones, sandstones and conglomerates hues 5 Y and N, chromas 0 to 2 and lightness categories 5 to 7 are typical.

In the terminology of Pettijohn (1957), the green beds consist of moderately to well sorted, fine to coarse-grained, glauconitic subarkoses and subgreywackes, with a minor amount of non-glauconitic calcareous protoquartzites and orthoquarzites. The latter tend to occur in the lower part of the Spinney Hill Sandstone, becoming more common northwards, and also in the basal Joli Fou sequence, where the Spinney Hill member is not developed. Conglomerates rarely exceeding a few centimetres in thickness are restricted to concentrations of cherts in calcareous protoquartzites and orthoquartzites, intraformational conglomerates consisting of fragmented concretions and redeposited mudstone and sandstone, and at the base, redeposited Mannville material. On the other hand, the drab beds of the Viking Formation, in addition to moderately to well sorted protoquartzites, subgreywackes and scarce orthoquartzites, include variably sorted conglomerates, sandstones, siltstones and mudstones with admixtures of relatively coarse-grained material. All of these frequently display vertical gradational relationships so that sharp contacts between different lithologies are rarely encountered (cf. Jones, 1961a, b). In the conglomerates, chert is an important constituent and clasts of intraformational origin are rare. The drab beds of the marginal belt appear to be mainly subgreywackes and protoquartzites though diamictitic (Flint *et al*, 1960) sandstones and siltstones also occur.

The comparatively scarce layers of calcareous orthoquartzite and protoquartzite of the Spinney Hill Sandstone and lowermost Joli Fou Formation (Pl. I, Figs. 1 and 2) are usually very light grey (N 8) and consist mainly of subrounded to well rounded, monocrystalline quartz grains of the fine to coarse-sand grades. Polycrystalline quartz grains also occur. Sorting is usually good and frequently laminae, or groups of laminae, within beds of this type contain grains of similar size. Chert grains, often of coarse-sand, granule and pebble grades, are fairly common in the quartz-rich sandstones, though usually accounting for no more than 10 per cent of the rock. Plagioclase is scarce and usually of fine-sand size. Rare, well-rounded glauconite pellets are also seen. Cement is usually calcite, which encroaches upon quartz grains giving rise to corroded grain margins; pyrite also occurs as a cementing agent of restricted distribution. Calcareous shell material is restricted to small, scarce prismatic fragments of pelecypod valves. Phosphatic fish bone fragments and teeth occur as scattered clasts or as concentrates at the interfaces of layers. Quartz-rich layers may reach thicknesses of up to 30 cm in the Spinney Hill Formation, but most frequently are no more than a few centimetres. They form discrete intercalations in mudstone and grain aggregates within glauconitic sandstone.

The green beds are largely made up of greyish green (10 GY 5/2), dusky yellow green (5 GY 5/2), dark yellowish green (10 GY 4/4) and light olive (10 Y 5/4), very fine to coarse-grained, glauconitic subarkoses and subgreywackes (Pl. I, Fig. 3), intercalated with dark grey (N 3) mudstones (Edwards, 1960). Pale olive (10 Y 6/2) and moderate greenish yellow (10 Y 7/4), usually fine-grained sandstones of these types with reduced glauconite content also occur. The sandstones exhibit moderate to good sorting. Quartz grains are generally subrounded to well-rounded in the relatively scarce medium and coarse-grained sandstones, but mostly subangular in the fine and very fine grades. Quartz grains are for the most part monocrystalline and frequently display undulose extinction; polycrystalline grains account for less than 5 per cent of the total quartz content which varies from 65 to 75 per cent. Microcline and orthoclase, with minor albite as frequently corroded and partially altered grains, account for up to 25 per cent of the rock. Glauconite occurring both as well-rounded pellets with random cryptocrystalline internal organization (Pl. I, Fig. 4) and as amorphous matrix make up as much as 20 per cent of the rock. Muscovite ranges from trace amounts to 4 per cent, and biotite occurs in trace amounts only. Calcite is the main cement in the well indurated, medium and coarse-grained sandstones. It also occurs sporadically in the variably indurated, matrix-bound, finer-grained sandstones, in which siderite and authigenic pyrite are also found as subordinate cements. Apatite, zircon, tourmaline, ilmenite and epidote are rare accessories.

Protoquartzites and subgreywackes of the Viking Formation (Pl. I, Figs. 5 and 6) are moderately to well sorted, very fine to coarse-grained sandstones, commonly light olive grey (5 Y 6/1), yellowish grey (5 Y 7/2) and also medium light grey (N 6). Very fine and fine-grained, light olive grey sandstones are the most frequent, consisting largely of subangular grains of monocrystalline quartz and subordinate polycrystalline quartz and chert, which may constitute up to 80 per cent of the rock. Corroded microcline and albite grains generally make up less than 3 per cent and are sometimes present only in trace amounts. Glauconite is frequently present in the form of rounded pellets, usually amounting to less than 5 per cent, but in places along the Dodsland-Hoosier trend up to 25 per cent. Muscovite usually amounts to less than 5 per cent of the rock. Trace amounts of epidote, zircon and tourmaline occur. Clay matrix is extremely variable, but is generally less than 15 per cent. Calcite is locally abundant as a cementing agent, as is microcrystalline siderite. Pyrite is commonly present in trace amounts but in places forms the only cementing material. In the medium and coarse-grained sandstones, rounded and well rounded, microcrystalline quartz and chert make up most of the rock. Polycrystalline quartz is scarce. The grains are cemented by sparry calcite, and often each pore is filled by a calcite crystal; some individual crystals may envelop several grains. Corrosion of quartz and chert grains by calcite is extremely common. Some of the corroded quartz grains appear to have been well rounded with quartz overgrowths. Drab fine-grained and very fine-grained sandstones are found also as thin beds in the Big River and uppermost Joli Fou mudstones. The poorly indurated, fine-grained St. Walburg sandstones (Pl. II, Figs. 1 and 2) and the unconsolidated Flotten Lake Sand are also mostly protoquartzite - subgreywacke.

Moderately to poorly sorted, very fine to coarse-grained sandstone and sandy siltstones of the Viking Formation are mostly light olive grey (5 Y 6/1) with varying proportions of scattered, brownish black (5 YR 2/1) chert granules and pebbles and intercalations of dark grey (N 3) mudstone. These diamictitic sandstones, though they may exhibit considerable variation even within a given hand specimen, as whole units tend to exhibit a regular downward decrease in the proportion of pebbles and granules, decrease in maximum and modal sand sizes and increase in mud content. The relatively coarse-grained bodies are often extensively cemented by calcite, siderite, quartz and occasionally pyrite, and present a striking contrast to the moderate to poor induration of the remaining, finer-grained parts.

Siltstones occur as discrete intercalations in mudstone sequences and as layers marking the repetitive gradations from fine and very fine-grained sandstones to overlying mudstones throughout the Lower Colorado.

Siltstone and silty mudstone also make up a major proportion of the fine-grained poorly sorted sandstones in the lower part of the Viking Formation. They occur also in thin layers, often with scattered granules and small pebbles, in the uppermost part of the Viking Formation and also in the sands of the St. Walburg and the basal Joli Fou. The last-mentioned frequently incorporate numerous, closely spaced, interconnected mudstone partings and continuous mudstone intercalations, and sand-grade sediment generally occurs as irregular pods and flattened lenses, often with gradational boundaries. In general, Lower Colorado siltstones appear to approximate in composition the subgreywacke and subarkose sandstones with which they are associated in a given stratigraphic unit, the main difference being an increased ratio of quartz to other framework minerals. Matrix material takes on a greater importance as a binding agent in both drab and green sediments. In the latter, for example, glauconite is mainly amorphous. Quartz occurs mostly as subangular, monocrystalline grains. Frequently abundant muscovite flakes in the better sorted siltstone layers and mudstone partings in the poorly sorted layers impart an irregular platiness to the rocks. Calcite cement, siderite impregnation of siltstone intercalations in mudstone units and pyrite in very thin layers are often seen.

Conglomerates

Conglomerates are best developed in the Viking Formation within and to the south of the Dodsland-Hoosier production trend. Occurrences in other units are for the most part restricted to very thin beds, often as solitary laminar aggregates in fine-grained rocks. Granules and pebbles, with varying proportions of sand, silt and clay predominate. However, cobbles 8 cm and more in length, are locally abundant. The clasts frequently exhibit a brownish black (5 YR 2/1) or olive black (5 Y 2/1) patina and, depending on the amount of finer-grained sediment present, the colour of the rock may vary from predominantly brownish or olive black to largely light olive grey (5 Y 6/1). They consist largely of chert, though polycrystalline quartz, jasper, silicified wood, plagioclase, sideritic silty mudstone and resedimented phosphate nodules are also present. The coarse clasts are frequently rounded to well-rounded, whereas associated sand-size particles tend to be dominantly subangular. Tabulate and bladed forms appear to be most common and surfaces are generally smooth, though minor irregularities arise from pressure solution, corrosion by calcite cement and penetration by pyrite crystals. Some pebbles exhibit well developed chatter marks over the entire surface, as from 709.6 to 710.2 m in the Canus Amoco Ulster Teo 6-2-29-24 well (Lsd 6-2-29-24W3). Pebbles of phosphatised wood are almost invariably elongate parallel to the lineation imparted by bundles of well preserved cells (Pl. II, Figs. 3 and 4) and wood fibres are easily recognized in the absence of a patina. Traces of browsing and boring by invertebrates were occasionally noted on the surfaces of larger pebbles and these features always antedate the patina.

Mudstones and Shales

The mudstones are mostly blocky and flaky but exhibit fissility approaching shale in parts of the Lower Colorado where the amount of silt and sand is reduced. This particularly applies to the upper part of the Big River and the lower part of the Joli Fou Formations. Medium dark grey (N 4) and dark grey (N 3), non-calcareous mudstones with subordinate intercalations of dark siltstone and predominantly very fine and fine-grained sandstone account for most of the succession. They also contain coquinas, bentonite layers and several different types of concretion. These mudstones form partings and intercalations in the sandstone layers and sandstone/mudstone pairs in the Big River and Joli Fou Formations of the north, as well as in the Viking Formation. Greyish black (N 2) mudstones are intercalated in the Spinney Hill Sandstone, and also characterize the lowermost Joli Fou Formation where the former unit is not distinguished.

Medium dark grey (N 4), calcareous mudstones with finely comminuted pelecypod debris occur throughout the Lower Colorado succession, but are particularly common in the upper part of the Big River Formation. The Second Speckled Shale of the Upper Colorado sub-group consists of medium dark grey (N 4) and dark grey (N 3) mudstones, in places bituminous, with incorporated layers of micrite flakes that range in size from a few microns to over 25 mm. These flakes, mostly silt and sand grades, are very light grey (N 8) and light grey (N 7), though light bluish grey (5 B 7/1), pinkish grey (5 YR 8/1) and yellowish grey (5 Y 8/1) are seen. They are coccolithic (Goodman, 1951) and widely distributed throughout the Western Canada basin (see also Langhus, 1971). Layers of pelecypod and foraminiferal debris are also intercalated (Pl. II, Figs. 5 and 6), and these extended as layers no more than a few centimetres thick, into the uppermost Big River shales.

Medium dark grey (N 4) and dark grey (N 3) carbonaceous mudstones occur in the lowermost part of the Joli Fou Formation throughout the study area and in the Viking in the extreme southwest. The carbonaceous material is coalified plant debris, occurring as finely comminuted particles and flakes up to several centimetres in length. Also incorporated, particularly in the lower part of the Big River Formation, are solitary laminae of quartz sand. These are largely subangular and subrounded, though rounded and well-rounded, frosted grains are fairly common. Laminar aggregates of rounded and well-rounded coarse sand, granules and small chert pebbles are also present, frequently in association with fish skeletal remains and pelecypod debris.

Bentonites

Bentonites occur throughout the Lower Colorado succession, but appear to be particularly numerous and well developed as intercalations in the lowermost Big River shales and in mudstones, sandstone/mudstone alternations and poorly sorted sandstones of the Viking Formation. They range in thickness from less than 3 cm to more than 60 cm and the thicker beds give characteristically high radioactivity and low resistivity responses on geophysical well logs. Lower Colorado bentonites are bluish white (5 B 9/1), white (N 9) and very light grey (N 8) and less commonly light greenish grey (5 G 8/1). They frequently grade upward through light grey (N 7) and light bluish grey (5 B 7/1) bentonitic mudstone into medium dark grey (N 4) and dark grey (N 3), argillaceous, non-bentonitic mudstone. Abundant small shards of volcanic glass and biotite flakes are commonly found where the bentonite is least diluted. Some bentonite layers incorporate spherical pyrite bodies up to 12 mm diameter, e.g. the base of a 30 cm bentonite layer within the Viking Formation at 603.2 m in the Cdn Sup Alminex Sanctuary 6-31-23-15 well (Lsd 6-31-23-15W3). Dark grey mudstone may form intercalations in bentonite and bentonitic mudstone and also as infill within networks of tubes and groups of biogenic cuspate laminae. Bentonite layers within the poorly sorted sandstone units are generally no more than a few centimetres thick and contain a relatively high proportion of sand. The abundant montmorillonite noted in the poorly sorted sandstones is also likely to have originated as volcanic ash.

Coquinoidal Material

Pelecypod debris, ranging from whole, disarticulated valves to single calcite prisms, is common throughout the Lower Colorado. Accumulations are never more than a few centimetres thick and occur as coquinas in the green sandstones of the lower Joli Fou. These deposits range from thin, relatively scarce sandy glauconitic pelecypod biosparite (Folk, 1962) with variable amounts of pyrite and collophane to shelly subgreywackes and subarkoses. Coquinoidal sideritic siltstones and silty mudstones are fairly common in the Joli Fou Formation. Scattered layers of *Inoceramus* calcite prisms are found in the mudstones, particularly in the upper part of the Big River Formation where they constitute a major proportion of the pelecypod-foraminiferal biosparites and biomicrites (Pl. II, Figs. 5 and 6). Ostracode carapaces and foraminiferal tests are locally abundant, especially in the lower part of the Joli Fou Formation, but always constitute accessories in the mudstones and fine-grained sandstones.

Fish-Skeletal Debris

Common scales and skeletal debris of fish occur throughout but are especially abundant in the Fish-Scale Marker of the upper part of the Big River Formation, where mudstones and siltstones and scarce fine-grained sandstones rich in fish remains (Pl. III, Fig. 1), give a series of positive responses on resistivity and radioactivity well logs. The fine-grained sandstone of this marker bed, however, is no more than a few centimetres thick. Far more common are laminar aggregates of fish skeletal debris in siltstones and silty mudstones which may consist of packed fragments forming continuous layers or of scattered particles in intermittent layers. The fish remains consist of abundant scales and teeth, vertebrae, bones displaying varying degrees of breakage and rounded bodies presumed to be otoliths. In most cases the calcium phosphate of scales and skeletal material appears to have undergone little, if any, diagenetic change, though pyritized vertebrae together with unaltered bone phosphate are relatively common. Throughout the greater part of the Lower Colorado laminar aggregates of fish remains predominate and are frequently associated with scattered granules and small pebbles of chert. Fish remains also tend to be associated with fine-grained, quartz-rich, calcite-cemented sandstones in the lower part of the Joli Fou Formation.

Plant Fragments

Coalified plant debris is extemely common in sandstones and in mudstone breaks within sandstone layers of the Viking Formation in the southern part of the study area. The plant debris ranges in size from finely comminuted particles disseminated throughout thin layers of carbonaceous mudstones to cobble-size clasts within the sandstone units. Carbonaceous mudstones containing also the larger lath-like fragments are fairly common as breaks in the thick sequences of relatively well sorted, fine-grained Viking sandstones. The larger fragments are frequently pyritized, are up to several centimetres long and exhibit well preserved patterns of wood fibres. Vitrinite flakes, rounded granules, pebbles and cobbles and lenses are fairly common. Occasionally, broken pebbles of this type exhibit the conchoidal surfaces characteristic of jet. Well-rounded pebbles of dark yellowish orange (10 YR 6/6) and moderate reddish brown (10 R 4/6) amber were observed in some poorly sorted sandstone units. Carbonaceous mudstones are largely restricted to the basal part of the Joli Fou Formation, where they may reach thicknesses of several centimetres.

Cements

Strongly positive resistivity responses, especially on focused resistivity logs, arise where relatively well indurated parts of sandy and conglomeratic units are encountered. This induration reflects several cementing agents, namely calcite, siderite, pyrite and a variety of apatite, occurring separately or as associations of two or more types. In the Spinney Hill Sandstone, the more extensive distribution of calcite cement is largely confined to medium to coarse-grained subarkoses and subgreywackes throughout the sequence and to fine to coarse-grained calcareous orthoquartzites and protoquartzites near the base. Siderite-rich layers in this sequence appear to have arisen through impregnation of fine-grained sandstones (Pl. III, Fig. 2), whereas pyrite cement occurs only as patches in fine to coarse-grained sandstones representing all degrees of induration. Phosphate is relatively scarce but appears to be often associated with calcite in medium to coarse-grained subarkoses and subgreywackes. The relatively coarse-grained upper parts of poorly sorted Viking sandstone units are cemented by siderite and calcite. Pyrite may also occur. Calcite is of particular importance in the comparatively well sorted thick sandstones (Pl. III, Fig. 3). Single, large calcite grains may enclose several sand particles and fill the interparticulate space, such as at 700.7 m in the Viking Formation of the Canus *et al.* N. Verendrye 12-32-28-23 well (Lsd 12-32-28-23W3). There rounded, and often hollow bodies, each with a moderate yellowish brown (10 YR 5/4) skin (Pl. III, Figs. 3 to 6), occur in the pores often in contact with clastic grains, and often as floating forms in the calcite cement. Flattening of these bodies is seen at the contacts with quartz and chert grains, and are reminiscent of contacts between fluid droplets and solids. This suggests that they may be relict hydrocarbon globules formed at a late stage in cementation of the rock and after the escape of volatiles (cf. Rupp, 1969).

Concretionary Siderite

Concretionary layers of ferruginous siltstone and ferruginous silty mudstone, ranging in thickness from less than 25 mm to 60 cm or more, give positive resistivity responses, in contrast to the flanking argillaceous mudstones with thin sandstone intercalations. Such ferruginous layers occur sporadically in the Joli Fou Formation but were not observed in the upper part of the Big River Formation. They frequently incorporate siltstone and sandstone intercalations in mudstone, impregnated with microcrystalline siderite and ankerite. In the Joli Fou Formation, concretionary ferruginous layers often include pelecypod debris, and locally phosphate nodules. Such layers in the lowermost Big River and uppermost Viking Formations frequently contain yellowish grey (5 Y 8/1) spherulites ranging from 1 to 12 mm in diameter and made up of gently curved, prismatic crystals, usually radiating from a central void (Pl. IV, Figs. 1 and 2). Some elongate crystals are also apparently oriented normal to the direction of radial growth. Powder X-ray diffractometry (P. L. Broughton) of samples representing cross-sections of individual spherulites indicates the presence of siderite. Furthermore, samples with spherulites, boiled in equal volumes of alizarin red S and 30 per cent NaOH solutions (see Wolf *et al.*, 1967, p. 267), took on the black stain characteristic for siderite; staining was patchy in the matrix, strong in the innermost and outermost parts of the spherulites and variable in the rest. Samples heated in an acidic solution of potassium ferricyanide (Dickson, 1966, p. 493 - 495) gave patchy turquoise stains in the matrix and in parts of spherulites with reduced siderite content, indicating the presence of ankerite. The spherulites may be partially or entirely replaced by pyrite.

Ferruginous Oolites

Oolites are extremely scarce and appear only near the base of the Joli Fou Formation. Two such instances were recorded by Maycock (1967, p. 34) from samples taken between 786.4 and 789.4 m in the Phillips Pete Noremac No. 1 well (Lsd 6-29-24-22W3), and between 701 and 704.1 m in the Sohio Peter Wartime No. 1 well (Lsd 2-14-26-17W3). The ooids consist of concentric sideritic layers, enveloping subangular to rounded quartz grains, and are cemented by calcite and patchy pyrite (Pl. IV, Figs. 3 and 4). Ooids are frequently replaced by pyrite.

Stratiform and Nodular Pyrite

Pyrite is widespread as an accessory, replacement of other framework components, as a cement of sporadic distribution in sandstones and conglomerates and as nodular and stratiform concretions. Stratiform pyrite concretions are up to several centimetres thick and frequently incorporate abundant fish skeletal debris and chert pebbles (Pl. IV, Figs. 5 and 6; Pl. V, Fig. 1). Nodular pyrite concretions often surround parts of burrow systems and replace concretionary bodies.

Nodular Phosphorite

Nodular phosphates are largely confined to the upper part of the Joli Fou Formation, where they occur as concretions in mudstones and as redeposited nodules and phosphate-impregnated intraformational clasts within sandstones. Nodules may be brownish black (5 YR 2/1) with a yellowish grey (5 Y 8/1) rind commonly up to 8 mm thick. X-ray powder diffractometry of nodules of this type (analyses by P. L. Broughton) indicates apatite, possibly dahlite. In some cases, the phosphorites are brownish black, spherical or ellipsoidal ranging in size from fine silt to medium sand and enclosed in a yellowish grey, microcrystalline matrix (Pl. V, Figs. 2 to 5). Silt and fine sand-size, subangular and rounded, monocrystalline quartz grains in varying proportions are also incorporated. Broken nodules exhibit conchoidal fracture surfaces. Nodules are usually cigar-shaped and up to 8 cm long; some are coalesced into composite forms, and some contain abundant radiolarians and indeterminate fibres replaced by phosphate. Viking phosphate pebbles, particularly those near the base, exhibit a black patina and have the external appearance of chert particles so common in that sequence. However, examination under the microscope reveals the presence of phosphate-impregnated spherulites, abundant radiolarians (Pl. V, Fig. 5) and quartzose silt and sand in a microcrystalline phosphatic matrix. One cobble-size phosphate nodule, presumably resedimented, at 746.5 m in the Kewanee Kindersley 11-29-29-25 well (Lsd 11-29-29-25W3) exhibits branching, shows two layers of patina separated by phosphate and displays numerous borings normal to the surface.

In the Spinney Hill Sandstone and its sandy equivalents in the Joli Fou Formation, phosphate occurs as impregnations of relatively well sorted sandstone layers. It consists of broken and resedimented phosphate nodules and rolled, phosphate-impregnated clasts derived through erosion of Spinney Hill sands. These clasts mostly occur as rounded pebbles, but cobbles up to 10 cm long were observed. Fine to coarse-grained, usually glauconitic sandstones, sometimes laminated and often containing large fragments of pelecypod valves, form those clasts which, regardless of composition, have a brownish black patina on the outer surface. Some sandstone clasts exhibit discontinuous, concentric, compositional zoning, reflecting different stages of sand acretion. They frequently display a complex replacement relationship between phosphate (Pl. V, Fig. 6), calcite and pyrite cements. Plate VI shows three such pebbles (Pl. VI, Figs. 1, 2 and 3) from the Spinney Hill Sandstone of the Ceepee Daniels 6-29 well (Lsd 6-29-31-19W3); the surface of a bored clast of phosphatized wood (Pl. VI, Fig. 4) and a banded-chert pebble (Pl. VI, Fig. 5), are shown for comparison. The clasts of chemical origin vary from angular to well rounded and often enclose fish skeletal debris and concentric arrangements of quartz grains.

Vein Barite

A zone of barite veinlets is reported in the Big River Formation, at the Duval Corporation Potash Shaft No. 1, near Saskatoon (Price and Ball, 1971).

Provenance of Siliciclastic Material

Glauconitic sandstones of the Spinney Hill increase in a northerly and northeasterly direction as the sequence increases in thickness, in contrast to the thickness decrease displayed by the Lower Colorado as a whole. It is therefore reasonable to conclude that the source land lay to the north of the present erosional edge, i.e. the Precambrian Shield of northern Saskatchewan (Edwards, 1960). Undulatory extinction of quartz grains, increase of polycrystalline quartz northward, the relative abundance of feldspar, and trace amounts of apatite, zircon, tourmaline, ilmenite and epidote are indicative of derivation from an igneous-metamorphic terrain. It is likely that the quantitatively subordinate quartz-rich rocks intercalated with the green sediments, especially in northern beds of the Spinney Hill and equivalents, arose through localized winnowing. This gains support from the frequent association of these rocks with concentrations of biogenic phosphate particles. However, the possibility exists of derivation through erosion of quartzose Upper Mannville sandstones, particularly in the lowermost Joli Fou Formation, where lithologies closely resembling those of the Pense Formation and continental Mannville sequence are fairly common (Maycock, 1967, p. 67).

Gross facies relationships are likewise of prime importance in the determination of possible source-areas for the Viking clastics. In the study area these sediments wedge out northeasterly into mudstones and siltstones in the northern part of the central facies zone (Jones, 1961a, b). This relationship appears to be widespread in southern and central Alberta (Badgley, 1952; Gammel, 1955). A western or southwestern source for the Viking, as well as equivalent sandstones in the uppermost Joli Fou and lowermost Big River sequences respectively, is acceptable (Fig. 30). The precise petrographic identity of the source rocks, however, is less easily determined. Viking quartz grains sometimes exhibit intermittent overgrowth of authigenic silica around well rounded particles, and calcite corrosion affects both overgrowths and original grains, so that derivation, at least in part, from pre-existing sandstones is a possibility. Abundant chert grains are not restricted to the Viking, but also occur as thin concentrations in the Big River and Joli Fou Formations, as well as in the Cessford Sand at the base of the Colorado Group, and Bow Island Formation (ASPG Leixon Committee, 1960) of southern Alberta, and in the Pelican Formation of central Alberta (Badgley, 1952). In northern Montana, chert pebbles form thin layers at the tops of sandstones in the predominantly marine Blackleaf Formation. A southwesterly palaeo-current trend for the lower sandstones and a southeasterly trend for sandstones overlying the continental Vaughn Member are indicated (Cannon, 1966). The Birdhead Sandstone of the Skull Creek Shale also contains chert pebbles in south-central Montana and the eastern Bighorn Mountains of Wyoming (Wulf, 1962). Chert pebbles originating as nodules in Paleozoic limestones farther west are described from the Lower Dunkleberg of the Colorado Group of western Montana (Gwinn, 1960, in Paull, 1962), and Paull (*loc. cit.*) notes the occurrence of chert clasts in sandstones and conglomerates of the Muddy Formation in the Bighorn Basin, which are considered to have been derived from the vicinity of the Idaho batholith. These are in contrast to the paucity of chert in the Newcastle-Dakota strata farther east (Mackenzie and Poole, 1962). A west-southwest derivation, possibly from a number of Mississippian limestone sources, for the Viking chert clasts of the study area seems most likely.

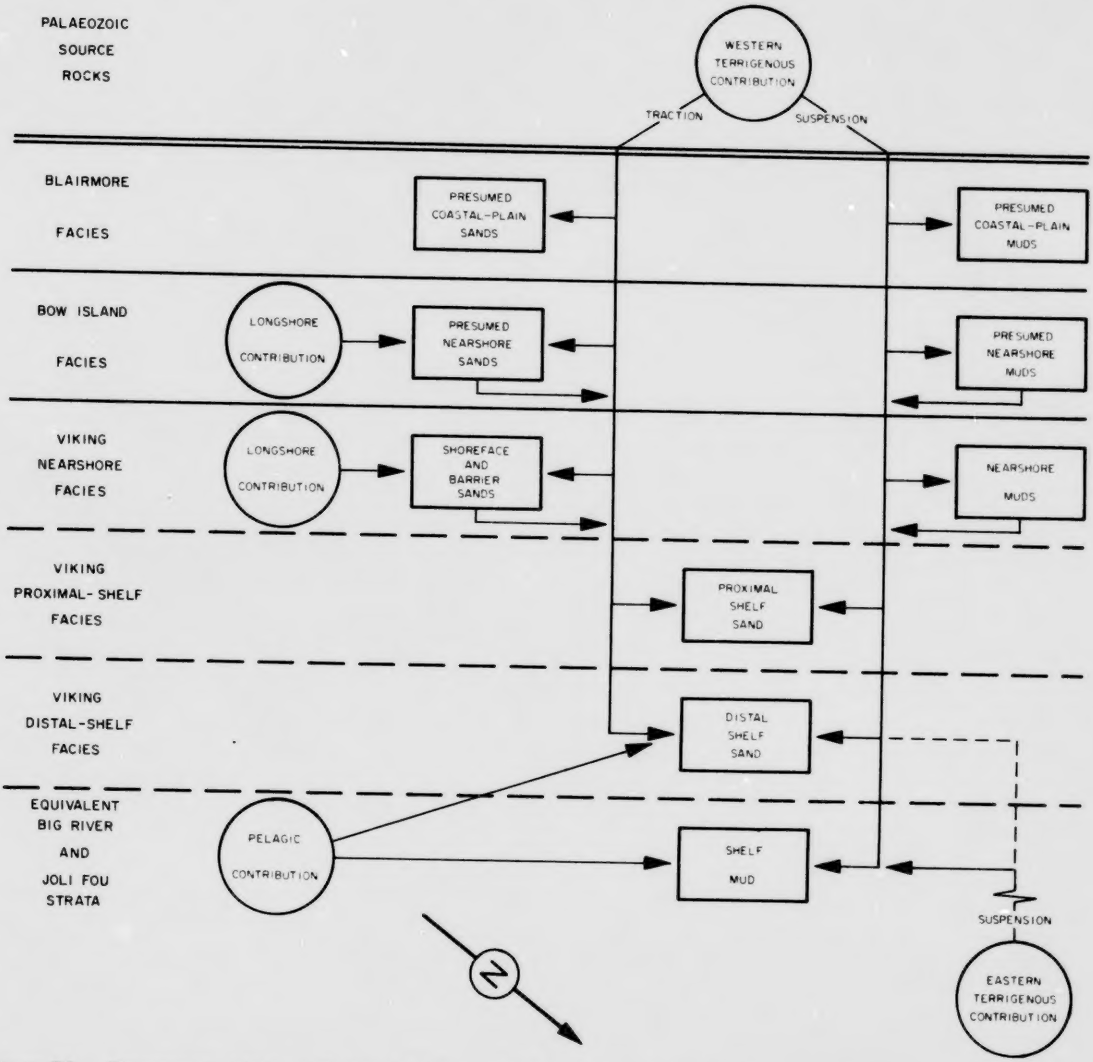

PALAEOZOIC SOURCE ROCKS
WESTERN TERRIGENOUS CONTRIBUTION
TRACTION
SUSPENSION
BLAIRMORE FACIES
PRESUMED COASTAL-PLAIN SANDS
PRESUMED COASTAL-PLAIN MUDS
BOW ISLAND FACIES
LONGSHORE CONTRIBUTION
PRESUMED NEARSHORE SANDS
PRESUMED NEARSHORE MUDS
VIKING NEARSHORE FACIES
LONGSHORE CONTRIBUTION
SHOREFACE AND BARRIER SANDS
NEARSHORE MUDS
VIKING PROXIMAL-SHELF FACIES
PROXIMAL SHELF SAND
VIKING DISTAL-SHELF FACIES
DISTAL SHELF SAND
EQUIVALENT BIG RIVER AND JOLI FOU STRATA
PELAGIC CONTRIBUTION
SHELF MUD
SUSPENSION
N
EASTERN TERRIGENOUS CONTRIBUTION

Figure 30 — Provenance of Lower Colorado siliciclastic deposits and principal modes of dispersal.

The Flotten Lake and St. Walburg of the sandy marginal facies belt both wedge out southward into Big River mudstones and siltstones. Information is scanty and no distinctive mineral species of wide distribution were found in the present study. However, in absence of other criteria, the northerly increase in sand content of the two units, as well as their northerly increase in combined thickness, are considered indicative of sediment supply from the north.

The Lower Colorado bentonites and bentonitic mudstones, are products of volcanic ash falls, presumably from sources in the Western Cordillera of the southern interior of British Columbia (Rudkin, 1964). Relatively coarse-grained volcanic debris appears to be largely restricted to the Crowsnest volcanics of southwestern Alberta, which attains a thickness of 490 m (Glaister, 1959). Bentonites are widespread in the Colorado mudstones; for example, Wulf (1962) notes the presence of bentonite intercalations up to 1.5 m thick in the Skull Creek Shale.

Sedimentary Structures

Layer Properties

Extrapolation of trends for reservoir sand bodies and of the fluid-flow characteristics of such sands, may be aided in large measure when attention is paid to sedimentary structures:

(1) The three dimensional, internal and external geometries of successive units, as defined by attitude of grain aggregates and lithologic discontinuities, to a large extent reflect the organization of grains by currents. Particular sedimentary structures and their vertical variation in type, or the composition of associations of structures, provide information as to the hydraulic properties of depositing currents (see, for example, Harms and Fahnestock, 1965). This gives a clearer insight into the depositional environment, which in turn may aid in the proper contouring of individual sand bodies and of larger, regional facies.

(2) Systematic study of stratification within a sand body helps to predict trends in primary reservoir heterogeneity (Johnson and Greenkorn, 1963; Montadert, 1963; Groult *et al.*, 1966). An obvious application is in tracing permeability barriers, such as shale breaks, and in the location of sandstone discontinuities resulting from the convergence of shale breaks (Zeito, 1965). Furthermore, vertical porosity and permeability gradients may coincide with patterns of change in type of internal sedimentary structure, and maximum lateral permeability may be related to the direction of movement of paleo-currents from which the sand body was originally deposited (Montadert, 1963; Hewitt and Morgan, 1965).

Stratification units are distinguished within the Lower Colorado sequence on the basis of angular relationships between superposed groups of grain aggregates, as well as by lithologic breaks. Units bounded by parallel surfaces, which may be erosional interfaces, and made up of groups of grain aggregates reflecting essentially constant or progressively changing conditions of sedimentation, are here termed beds. The thickness classification of stratification units employed in this account is that modified by Ingram (1954) after McKee and Weir (1953). The term "inclined stratification" is a general one, applied to all stratification inclined to the principal surface of accumulation (Potter and Pettijohn, 1963, p. 69). The scale of Lower Colorado inclined stratification is measured in a range of hundreds of microns to tens of kilometres; terminology adopted in the present account is based primarily on considerations of three-dimensional geometry and is essentially that used by Gradzinski (1970). "Cross-stratification" describes inclined stratification limited to a single sedimentation unit (as used by Jopling, 1964). The smallest unit of inclined grain aggregates is termed a set of cross-strata (McKee and Weir, 1953), while a coset is a grouping of superposed sets, comprising geometrically similar cross-strata (Allen, 1963, p. 98). Sets of cross-strata are here described in the terminology of McKee and Weir (1953) and Allen (1963), based on:

(1) magnitude (small-scale less than 5 cm, large-scale more than 5 cm);

(2) grouping (solitary, grouped);

(3) shape of the lower bounding surface (planar, trough, irregular);

(4) attitude with respect to the lower bounding surface of the set (angular, asymptotic, concordant);

(5) relation between the lower bounding surface and the stratification of the underlying set (parallel, non-parallel); after Crook, 1965.

Large-scale inclined stratification comprising oblique layers, themselves made up of sets and cosets of cross-strata, have been termed "composite" by Gradzinski (1970), who classified associations of structures of this type hierarchically, so that the composite unit is regarded as "second-order" and the individual sets and cosets as "first-order".

Sequence Elements

Some sedimentary sequences may be described in terms of vertically repeated elements (Vassoyevich, 1948; Simpson, 1970), defined by the layers and groupings of layers, which constitute the simplest components of vertical petrologic variation. Much of the Colorado Group may be described as repetitions of a small number of generalized sequence elements (Fig. 31; Simpson, 1971), each characterized by predominance of particular gross lithologies and associated sedimentary structures:

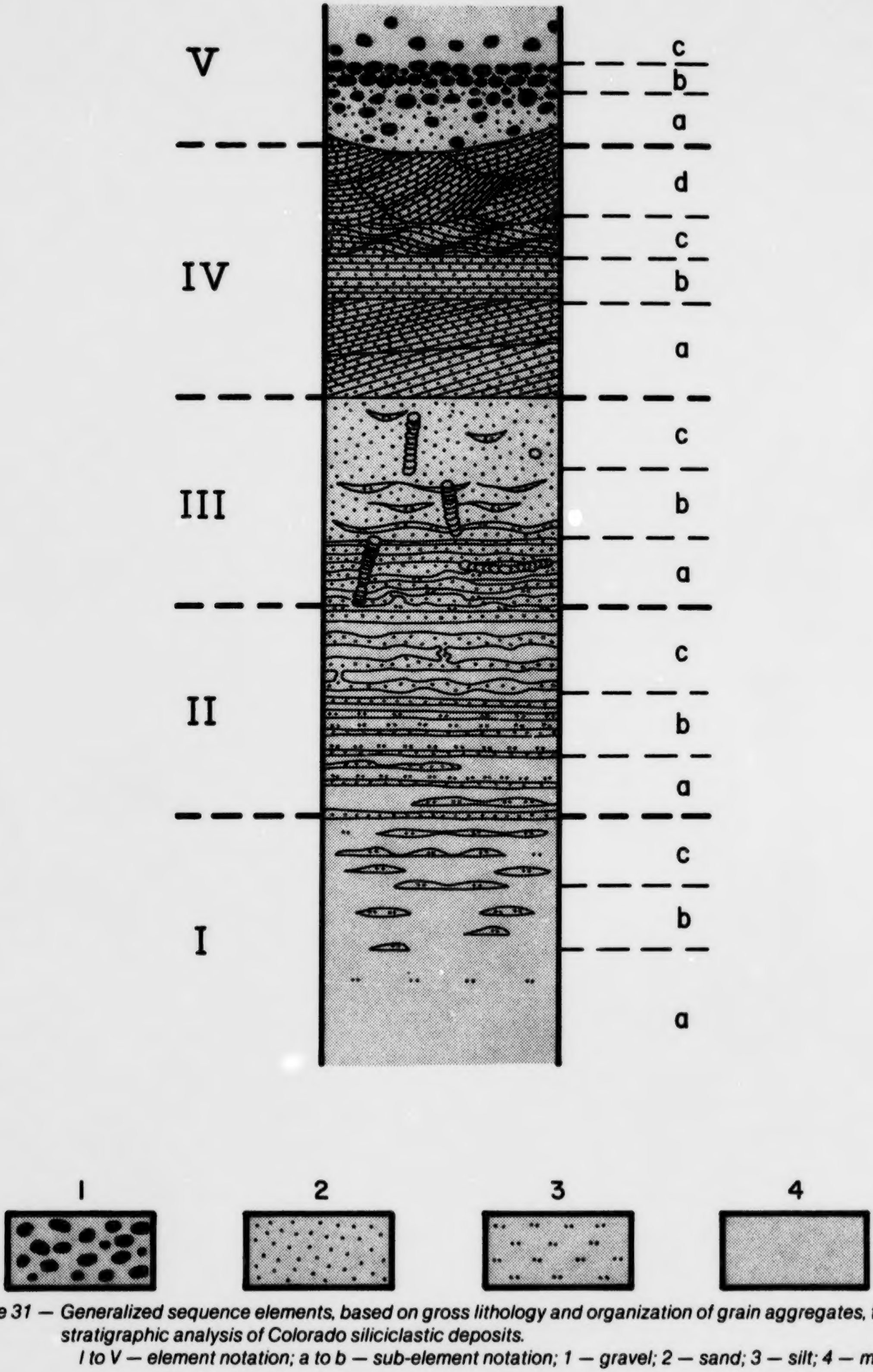

V
c
b
a
d
c
IV
b
a
c
III
b
a
c
II
b
a
c
I
b
a
1
2
3
4

Figure 31 — Generalized sequence elements, based on gross lithology and organization of grain aggregates, for stratigraphic analysis of Colorado siliciclastic deposits.

I to V — element notation; a to b — sub-element notation; 1 — gravel; 2 — sand; 3 — silt; 4 — mud.

I — a mudstone element, comprising a largely structureless mudstone-shale sub-element (a); a mudstone-siltstone sub-element (b) with relatively coarse grains forming scarce lenses; a mudstone-siltstone sub-element (c) with concentrations of relatively coarse grains in fairly common lenses and intermittent layers.

II — a siltstone element, with a lenticular-layered siltstone-mudstone sub-element (a); a siltstone-mudstone sub-element (b) in which layering is predominantly wavy and simple; a sandy siltstone-mudstone sub-element (c), in which layering is mainly wavy and composite.

III — a silty sandstone element, consisting of a more silty sub-element (a); an intermediate sub-element (b); and a more sandy sub-element (c); all displaying variable disruption of wavy and flaser-type layering by loading and injection phenomena, as well as by the burrowing activities of organisms.

IV — a sandstone element, which may exhibit dune-scale, inclined laminae (a); horizontal laminae (b); ripple cross-laminae (c); and trough cross-laminae (d).

V — a conglomeratic element, including pebbly sandstones (a); conglomerates (b); and pebbly mudstones (c); all of which frequently display inverted grading of relatively coarse grains.

The subordinate lithologies include coquinoidal deposits, micritic mudstones, bentonites, ferruginous concretions, phosphatic nodules and concentrations of iron sulphides.

Advantages to be gained by using the numerical scheme of sequence elements outlined above are:

(1) It presents a means of describing in terms of only a few categories, a complex sequence of rocks, characterized by a wide range of particle sizes and considerable gradation in petrographic and textural properties, by taking into account only gross variation in these properties. Such variation may be related to signatures of geophysical well logs and used for correlation over relatively short distances. Furthermore, insofar as the scheme has to do with the nature and distribution of mudstone partings and intercalations and their relations to sandstone and conglomerate layers, it provides a measure of reservoir heterogeneity.

(2) Categories are based upon predominance of a particular sedimentary structure, or association of sedimentary structures, easily recognized in cores and related to the dynamics of flow at the site of deposition. Thus, a given sequence element provides a record of a depositional event, or of progressively changing depositional events. If one or more preferred vertical orders could be established for the elements on a regional scale, then this would reflect the patterns of sedimentation. Such relationships would constitute a useful exploration tool, where porosity and permeability gradients are related to particular elements.

A possible disadvantage of the scheme is the necessity for arbitrary decision in delineating the given elements, as a result of intergradation, especially in extremely fine grained sequences.

The composition of the Lower Colorado succession (Fig. 32) in terms of sequence elements is given below:

The Joli Fou Formation typically comprises type-I and type-II elements, with thin coquinoidal layers of pelecypods, aggregates of phosphate nodules and ferruginous concretions with siderite occurring as subordinate lithologies. Type-II elements are best developed immediately below the Viking Formation in the southwestern corner of the study area and in the west near the base of the sequence, where the Spinney Hill Sandstone is not developed. The Spinney Hill incorporates type-II and type-IV elements, with intercalations of type-I elements becoming numerous in the south. Sands of the Spinney Hill sequence develop by increase of type-IV elements.

The Viking Formation, where it is thickest in southwestern Saskatchewan, is characterized by all five sequence elements (*cf.* Jones, 1961a), frequently as repeated coarsening-upward beds. In the Bayhurst district, type-IV elements are widely distributed particularly at the top of the formation. Farther northeast, these elements are scarce or absent. Type-III and sandy type-II elements predominate northeast of the Bayhurst district, and occur with subordinate intercalations of muddy type-II elements and type-V elements. North and northeast of the Dodsland-Hoosier production trend, the sequence comprises muddy type-III and type-II elements with intercalations of type-I mudstones. The Flotten Lake Sand is unconsolidated in the upper part and the primary organization of grains cannot be determined. However, the presence of type-IV elements may be deduced on the basis of good sorting between the interval 180.4 to 189.3 m in the D.N.R. Flotten Lake No. 2 well (Lsd 4-10-65-17W3). Lower in this unit, type-II elements appear to predominate.

The Big River Formation consists of type-I mudstones with intercalations of muddy type-II elements, pelecypod-coquinoidal layers, concentrations of fish remains and ferruginous concretions with subordinate siderite. In the southwest, the Fish Scale Marker is well developed as type-II elements with numerous bone beds and intercalations of type-I mudstones. Farther northeast, however, the mud content increases greatly. In the north the St. Walburg sequence is made up of type-III and type-IV elements with intercalations of muddy type-II.

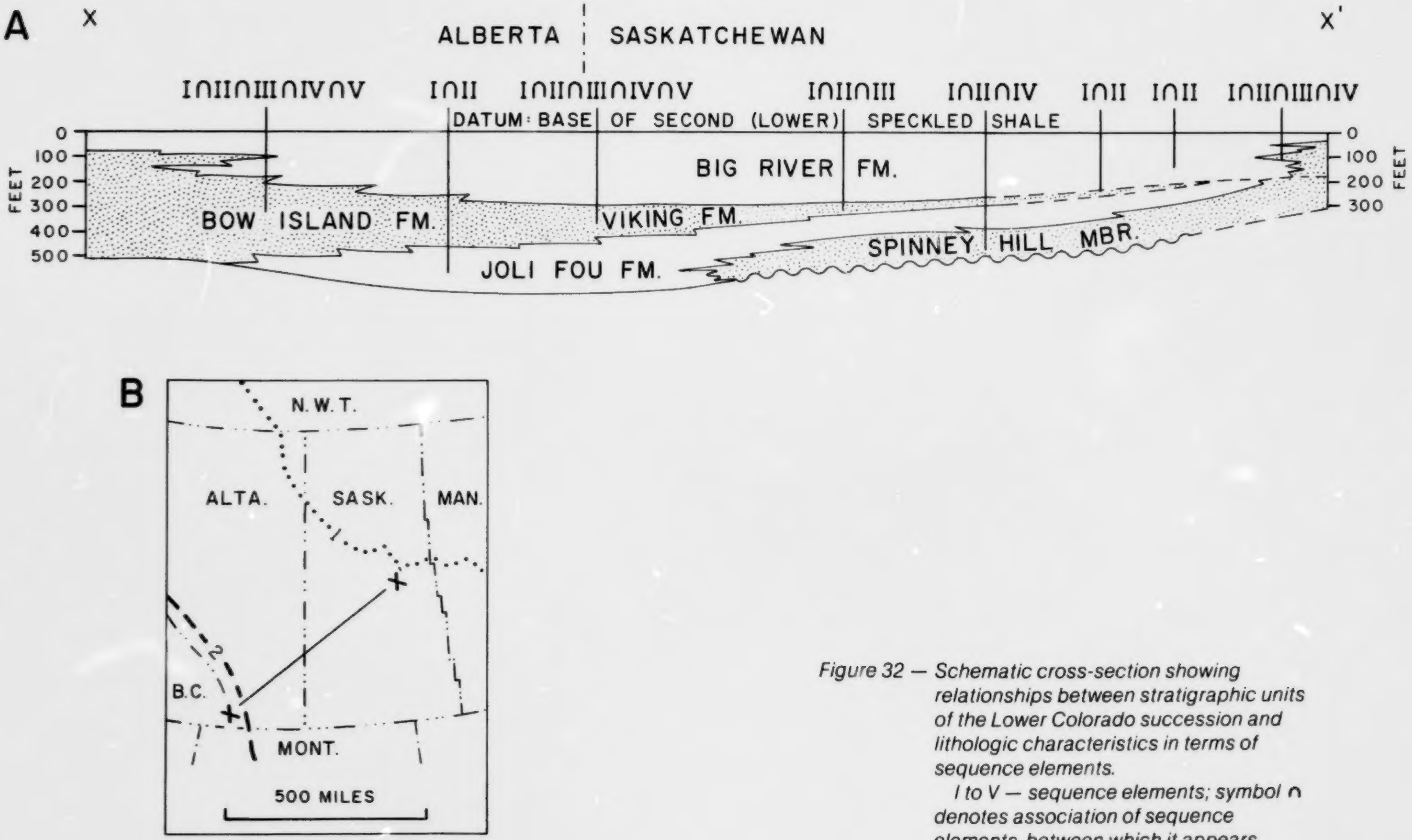

A
B
X
X'
ALBERTA
SASKATCHEWAN
I∩II∩III∩IV∩V
I∩II
I∩II∩III∩IV∩V
I∩II∩III
I∩II∩IV
I∩II
I∩II
I∩II∩III∩IV
DATUM: BASE OF SECOND (LOWER) SPECKLED SHALE
0
100
200
300
400
500
FEET
BIG RIVER FM.
BOW ISLAND FM.
VIKING FM.
SPINNEY HILL MBR.
JOLI FOU FM.
N.W.T.
ALTA.
SASK.
MAN.
B.C.
MONT.
1
2
500 MILES

Figure 32 — *Schematic cross-section showing relationships between stratigraphic units of the Lower Colorado succession and lithologic characteristics in terms of sequence elements.*

I to V — sequence elements; symbol ∩ denotes association of sequence elements, between which it appears.

Small-scale, Inclined Stratification

Flattened lenses of very fine and fine-grained sandstone enclosed in mudstone commonly occur in type-I and type-II elements throughout the Lower Colorado sequence. They may be solitary or grouped and overlapping peripherally upon adjacent lenses on the same surface of accumulation (Pl. VII, Figs. 1, 2 and 3). This bedding type has been termed lenticular bedding (Reineck and Wunderlich, 1968a). Each sand lens is a small-scale set of cross-laminae, making angular contact with a planar base which may be a tool-marked erosional interface. The top of the lens is slightly asymmetric in most cases. In some cross-sections solitary and grouped lenticular sets may exhibit horizontal and very gently inclined laminae. These structures result by the arrest of sand ripples moving into mud-coated troughs. Scarce ripples largely made up of laminae with unidirectional inclination, but with the laminae on one side truncated by sets of laminae opposite in inclination also occur; e.g. at 630.8 m in the Viking Formation of the Cdn-Sup Alminex Lacadena 6-21-23-16 well (Lsd 6-21-23-16W3; Pl. VII, Fig. 2). These resemble the asymmetric oscillation ripples of Newton (1968) and Reineck and Wunderlich (1968b).

Wavy bedding (Reineck and Wunderlich, 1968a) refers to slightly undulating, very thin mud layers separating successive grouped sets of sandy cross-laminae, angular and asymptotic to a planar base. Mud layers may die out laterally, so that successive sandy cosets make contact, giving rise to composite sandy units. These occur in type-II elements belonging to finer-grained parts of the Viking (Pl. VII, Fig. 4) and throughout the Joli Fou - Spinney Hill beds. They arise from burial of superposed sand ripples by mud, and cross-sections parallel to the ripple crests display alternations of mud and horizontal and gently inclined laminae of sand.

Type-III and sandy type-II elements of the Viking and Spinney Hill sequences include cross-laminated sandy units, which incorporate very thin mudstone and muddy siltstone partings and intercalations. The latter may be arcuate, concave-up and isolated or grouped, forming undulating networks of interconnected partings. The structure is termed flaser bedding and arises through deposition of mud over an entire rippled surface or ripple troughs only, forming during pauses in the current activity effecting ripple propagation (Hantzschel, 1936; Reineck, 1960). Vertical sections normal to the ripples exhibit sandstone cosets, made up of cross-laminae, both angular and asymptotic to planar and trough lower bounding surfaces. Parallel to the axes of ripples, on the other hand, sandstone laminae are for the most part concordant with the lower surfaces.

Sandstones with ripple and dune cross-stratification in the absence or near-absence of mudstone partings and intercalations are largely restricted to parts of the Viking, where it is thickest as a nearshore deposit in the southwest of the area, and to the Spinney Hill Sandstone in the east. Typically the planar lower boundary of a given set of tabular laminae truncates laminae of the underlying set at a low angle (Pl. VIII, Fig. 1) and cosets may be a metre or so in thickness, though less than 30 cm is more common. In the Spinney Hill such units comprise type-IV fine to coarse-grained glauconitic subarkose, as in the Ceepee Daniels 6-29 well (Lsd 6-29-31-19W3), and calcareous orthoquartzite as seen in the D.N.R. Big River No. 6 well (Lsd 5-10-55-7W3). At the former, groups of orthoquartzitic laminae, up to 25 mm thick and concordant with laminae of adjacent glauconitic subarkose are abundant. The Viking Formation also exhibits cross-stratification of this kind in well-sorted protoquartzites, usually fine-grained and with abundant calcite cement. These occur as components of type-IV elements near the top of the formation particularly in the Bayhurst district, as in the Imperial Bayhurst 6-16-24-25 well (Lsd 6-16-24-25W3) from 666.6 to 670.9 m. Cross-stratification in conglomerates of relatively well sorted type-V elements, is exemplified from 710.2 to 710.6 m in the Canus Amoco Ulster Teo 6-2-29-24 well (Lsd 6-2-29-24W3) and in type-V diamictites of the Imperial Smiley 15-5V-31-25 well (Lsd 15-5-31-25W3) from 721.5 to 721.9 m.

Ripple-drift cross-lamination is scarce in the Viking type-IV relatively well-sorted, fine-grained protoquartzites belonging to nearshore deposits in the southwest. It is recognized only in vertical section cut parallel to the current direction; in sections cut normal, lenticular bodies of laminae are observed. That in the Viking, as typified by an occurrence at 723.7 m in the Imperial Highbury 10-35-25-26 well (Lsd 10-35-25-26W3), is up to 15 cm thick and generally exhibits upward passage from sinusoidal ripple lamination to ripple-drift cross-lamination. It comprises climbing lee-side laminae and stoss-side laminae and laminae continuous between neighbouring ripples (Pl. VIII, Fig. 2; cf. Jopling and Walker, 1968). The units are frequently delimited by very thin muddy siltstone layers, which in several instances are occupied by burrows resembling *Spirophyton*, resting upon and passing upwards into flaser bedding. Ripple-drift cross-lamination is thought to reflect deposition from weak currents in conditions of abundant supply of sand and silt (Walker, 1963; McKee, 1965). Furthermore, Jopling and Walker (*op. cit.*) consider the association of sinusoidal ripple lamination and ripple-drift cross-lamination, to represent rapid deposition from suspension.

Small-scale trough cross-stratification is extremely common in Spinney Hill and basal Joli Fou type-II fine-grained sandstone, and in types-III, -IV and -V elements of the Viking Formation. They form grouped trough-like non-parallel sets, each made up of laminae tangentially inclined and concave-up with respect to the erosional lower surface. Trough cross-laminated beds may include sets widely different in mineralogy. For instance, in the lowermost Joli Fou of the Ceepee Dukesbury 13-18 well (Lsd 13-18-34-21W3) at 680.9 m and 682.4 m respectively, sets of quartzose, fine-grained sandstone truncate and are themselves truncated by sets of glauconitic subgreywackes (Pl. VIII, Figs. 3 and 4). Trough cross-stratification in the Viking Formation is frequently associated with abrupt vertical change in grain size, with pebbly material resting on the scoured surface and overlain by irregular laminae. Small-scale trough cross-stratification is considered to be related to ripples and spoon-shaped depressions associated with migrating linguoid ripples (Harms and Fahnestock, 1965).

Cross-lamination in the form of tabular foresets and trough infillings of microscopic dimensions is fairly widespread in type-I and -II layers of coarse siltstone and fine sandstone and in type-IV fine sandstones throughout the Lower Colorado. Micro-cross-lamination frequently occurs as a subordinate internal structure associated with horizontally laminated sub-elements, as in the St. Walburg Sandstone of the Cdn Seaboard Horse Head 9-28 well (Lsd 9-28-57-18W3). They occur as both solitary and grouped sets, occupying troughs no more than a few millimetres deep, such that the lower bounding surface of a given set is non-parallel with respect to underlying laminae, and the upper bounding surface is usually concave or sub-horizontal (Pl. IX, Fig. 1). Comparable cross-lamination is described from detrital limestones by Harbaugh (1959, Fig. 2, p. 33) and from horizontally laminated fine-grained sandstones in distal flysch by Simpson (1970, Pl. VIII, Fig. 4). Small-scale foresets of type-I and -II elements are usually made up of coarse siltstone or fine sandstone, but may also incorporate high proportions of skeletal debris or consist almost entirely of biogenic material (Pl. IX, Fig. 2). They frequently rest upon an irregular, erosional surface and exhibit pseudo-imbrication of the larger biogenic clasts. The upper surface of sets is generally horizontal.

Horizontal and Gently Inclined Lamination

Horizontal lamination occurs throughout the Lower Colorado in each of the five sequence elements. In type-I and type-II elements, it is seen as grouped laminae of silty mudstone and siltstone (Pl. X, Fig. 1), which may be associated with lenticular and wavy bedding. It also occurs as grouped or isolated very fine to coarse-grained sand laminae and intermittent laminae composed of sand, granules and pebbles in varying proportions (Pl. X, Figs. 2 and 3). To these occurrences may be added the intermittent laminae of fish remains and pelecypod debris, as well as the laminar aggregates of coccolithic flakes of the Second White-Speckled Shale. Horizontal lamination is developed in type-III elements of the Viking Formation as relatively scarce intercalations, usually no more than a few centimetres thick. Many of the well sorted type-IV elements of the uppermost Viking in the southwest of the study area display horizontal lamination, as in the Oliphant NWRCo Gorefield 3-27 well (Lsd 3-27-25-28W3) from 772.1 to 779.7 m. Crude horizontal laminae are also seen in type-V elements. The poorly consolidated fine-grained St. Walburg sands also exhibit near the top, horizontal lamination in type-IV elements, as in the Cdn Seaboard Horse Head 9-28 well (Lsd 9-28-57-18W3) below 248.4 m.

Pettijohn (1957) maintains that horizontal lamination in sediments reflecting a variety of current activity is indicative of pulsations in flow. However, it is shown experimentally by Jopling (1964) that alternating relatively fine and coarse laminae may be a result of constant flow and sediment discharge. Also, horizontal laminae are produced by ripples migrating across delta-like foresets (Jopling, 1966). Newton (1968) notes the occurrence of horizontal laminae beneath wave-formed ripples and considers the possibility of their having resulted from the migration of trains of wave-formed ripples. Wunderlich (in Reineck, 1967) considers the very thin mud layers of alternating sand and mud in the North Sea to have originated as bottomset laminations of ripples, and the sand layers to be remnants of straight, flat-crested ripples. These are attributed to fairly fast-flowing currents with a high suspended load (Reineck, 1967).

Horizontal and gently inclined lamination of fine-grained sandstone often grading upward into silty mudstone, are common in type-II elements of the lower part of the Big River, the Viking, the basal Joli Fou and the Pense Formations. The base of each layer is sharp and planar, though minor irregularities, which may be infillings of scours, do occur. Grading from fine-grained sandstone through siltstone to silty mudstone is often seen (continuous grading of Ksiazkiewicz, 1952), but sharp contacts between sandstone and overlying silty mudstone (discontinuous grading) are also common. Both sandy and muddy parts of layers are frequently about 25 mm thick. However, the sand content may be restricted to a few basal laminae and the siltstone, passing into mudstone, may account for most of the layer. Sharp tops of sandstone layers are frequently undulatory and associated with ripple lamination. Composite sandstone layers, often displaying multiple grading (Ksiazkiewicz, *loc. cit.*), are formed through erosion of the intervening mudstones, which may be preserved as intermittent partings (Pl. X, Fig. 1). The sandstones are frequently burrowed, a form allied to *Chondrites* being widespread. The units described above are best developed in the Pense and Viking Formations, where they often account for a metre or so of section. They appear to be identical to features described by Goldring (1966) from the Upper Devonian Baggy Beds of North Devon and considered by him to be diagnostic of a sub-littoral environment.

Structures in Conglomerates

Thin conglomerates occur with sandy siltstone to coarse-grained sandstone (all sequence elements) with scattered granules and pebbles. However, in the Viking Formation of the southern part of the study area, conglomeratic units are well developed as type-V elements, reaching a metre or more in thickness, and scattered granules and pebbles in finer-grained deposits representing all four remaining sequence elements are numerous. Likewise, diamictites comprise abundant, scattered granules and pebbles, for the most part floating in a matrix ranging in size from clay to coarse sand and variably admixed. Internal organization of coarse clasts is extremely variable. Mudstone layers with randomly oriented pebbles are frequently interbedded with conglomerate and sandstone exhibiting horizontal and gently inclined lamination (e.g. 721.5 to 721.9 m, Imperial Smiley 15-5V-31-25 well (Lsd 15-5-31-25W3)). Laminated conglomeratic units with abundant intercalations of mudstone and fine to coarse-grained sandstone are also common, as are diamictites with abundant mudstone at the base of the formation in the Smiley-Dewar region. From considerations of cores and resistivity logs, it seems that these units are about 1 m thick. However, cores displaying these features are usually characterized by poor recovery. Conglomerates and pebbly sandstones containing little or no mudstone are fairly common and display horizontal and inclined lamination, frequently resting with sharp erosional contact upon finer-grained sequence elements and displaying load deformation at the contact. Imbrication of pebble and cobble-size clasts is often seen in relatively thin type-V elements, as at 645.3 m in the Ceepee Dukesbury 13-18 well (Lsd 13-18-34-21W3).

Conglomeratic layers frequently form concordant intercalations with the other sequence elements, exclusive of type-III. In the latter case, granules and pebbles are frequently scattered throughout a given unit, becoming most numerous toward the top of the element (cf. Jones, 1961a).

Structureless Sediments

The dominant lithology of the Lower Colorado is medium dark and dark grey, frequently structureless mudstone, that fractures to give blocky fragments or angular chips and only in the uppermost Big River Formation do they approach the fissility of shale. Bedding is delineated by intercalations of bentonite, laminated siltstone and very fine and fine-grained sandstone and where these are scarce or absent, by intermittent, laminae of chert granules and small pebbles, layers of phosphatic nodules and concretionary ironstones, laminar aggregates of *Inoceramus* prisms or skeletal debris of fish and transected, single, flat-lying valves of large pelecypods. Indeterminate, flattened, carbonaceous and pyritized burrows, usually straight or arcuate and branching, as well as sand-filled, sand-lined and mud-filled forms are widely distributed.

The discontinuous laminar aggregates of bioclastic detritus are regarded as lag deposits concentrated by currents, probably fluctuating in strength. The coarse chert grains, are frequently associated with fish remains and their presence would appear to support an origin as a lag deposit. That traction currents were active is also shown by inclined laminae of quartz-silt in some phosphate nodules, e.g. 760.2 m in the Birsay Crown No. 1 well (Lsd 13-4-25-8W3). Further evidence comprises (1) ripples built up of laminae of silt-size, ovoidal phosphatic bodies, as in Joli Fou concretions at 493.9 m in the Duval Saskatoon 6-18-36-6 well (Lsd 6-18-36-6W3); (2) Viking erosion surfaces within sideritic ferruginous mudstones and siltstones at the Pennant Brock East 11-22-28-19 well (Lsd 11-22-28-19W3) at 720.2 m; (3) gradational boundaries between structureless mudstones and underlying bentonites of lighter colour. Such gradations are frequently made up of horizontal and gently inclined laminae or ripple cross-laminae, clearly visible as a result of colour differences between bentonite-rich and bentonite-poor laminae, developed both as separate sets and as superposed groups within individual sets.

Interfacial Structures

Interfacial structures are sole markings for the most part restricted to very thin and thin, fine-grained sandstone layers of type-II and scarce type-IV elements. These are found in the basal "transition beds", the Spinney Hill Sandstone (Maycock, 1967), the soles of relatively scarce type-II sandstone layers of the Big River Formation and on rare interfaces of Viking type-IV elements. Interfacial structures are the infillings or moulds of markings made on a soft cohesive mud surface through the activity of currents. It is likely that they are widely distributed throughout the Lower Colorado succession, occurring in most type-II elements.

However, the very thin, fine-grained sandstones and sandy siltstones are not easily distinguished from the underlying mudstones, in that the lithologic contrast at such interfaces is only slight.

The most common interfacial structures are tool marks, reflecting the impingement of current-borne objects upon the mud bottom. Among these, groove moulds are fairly common and are seen as the counterparts of straight and arcuate scratches on the mud surface (Pl. XI, Figs. 1 to 6). They are frequently 5 cm or more in length and often deepen gradually downcurrent then terminate abruptly. Only organic detritus has been found at downcurrent ends of groove moulds. This includes pelecypod debris, ranging from nearly complete valves to single calcite prisms of *Inoceramus*, foraminiferal tests, ostracode carapaces and skeletal debris of fish. Relatively scarce bounce and prod moulds, recording clast impingements of shorter duration, are associated with groove moulds. Tool marks occur at the flat interfaces of sandstone layers, which frequently are individual sets of ripple cross-laminae. In that the trend of a given association of tool markings is parallel to the current direction indicated by ripple laminae on the interface, it is likely that one current was responsible for both types of structure.

Scour marks record entrainment of bottom sediment through the differential scouring action of a turbulent current. They are seen in cross-section as small-scale depressions of the interface with an infilling of trough cross-laminae (Pl. XII, Figs. 1 and 2) or horizontal laminae. In the finer-grained type-II elements, horizontal fine-grained sandstone laminae may be entirely restricted to a series of depressions of the interface, overlain by laminated siltstone. On the bedding interface they are elongate and triangular flute moulds and also scour-modified pre-existing depressions, such as current-exhumed trails. Tool marks may occur in the walls of scours. Pelecypod debris and skeletal remains of fish make up the relatively coarse-grained clasts frequently concentrated at the interface.

Deformational Structures

Small-scale folds, affecting Viking type-I and type-II siltstone and fine-grained sandstone layers in the southern part of the study area, vary from gentle undulation to complex and recumbent and piled lumps of contorted detached beds, e.g. Canus Amoco Ulster Teo 6-2-29-24 well (Lsd 6-2-29-24W3) at 712.5 m (Pl. XIII, Fig. 1). Overfolding is also seen in the Spinney Hill of the Ceepee Riley Lake 3-4 well (Lsd 3-4-39-13W3) from 655.9 to 658.7 m. Detachment and contortion in the Viking of the Imperial Centrefield 13-10 well (Lsd 13-10-26-21W3) are shown in Pl. XIII, Fig. 2. The contorted sediments frequently are up to 30 cm thick and bounded by undeformed layers.

Vertical displacement of material from beds is represented by clastic dikes and sills best developed in the Joli Fou Formation, but also in the Viking and lowermost Big River sequences and also by load and injection deformations in the Viking and Spinney Hill strata. A well developed clastic dike is observed near the base of the Joli Fou sequence at 517.9 m in the Ibstone No. 3 well (Lsd 11-31-48-27W3), where a ferruginous concretionary layer incorporating a thin, load-deformed layer of calcareous orthoquartzite with abundant chert pebbles is transected for at least 23 cm by a near-vertical fissure up to 1 cm in width and filled with siltstone identical with the subjacent Mannville (Pl. XIII, Fig. 3). Highly contorted dikes (Pl. XIII, Fig. 4) of fine-grained glauconitic sandstone, rich in fine pelecypod debris, cut Spinney Hill type-II sandstone and mudstone layers below 709 m in the Canpet Braeburn 10-9 well (Lsd 10-9-31-20W3). Dike material with the enclosing mudstone removed exhibits strong contortion. The Joli Fou mudcrack fill of Jones (1961a) from 713.5 to 713.8 m in the Sun Eureka 2-7 well (Lsd 2-7-31-22W3), is found to have subsidiary sand-filled branches exhibiting contortion. Furthermore, the infilling sandstone displays a platiness parallel to its margins, possibly reflecting sand flow. The feature is accordingly here interpreted as a sand dike.

Load and injection structures are best developed in type-II and type-III elements of the Viking Formation and also in type-II elements of the Spinney Hill. Load structures are commonly seen as downward distensions of the lower surface of a relatively coarse-grained layer, where the latter overlies fine-grained sandstone, siltstone or mudstone, (Jones 1961a, Pl. IIIa, p. 63). Frequently associated with load structures are tongue-like injection of fine-grained material into an overlying coarser-grained layer. Laterally interconnected, sand-filled cracks penetrating thin mudstone layers (Pl. XIII, Fig. 5) in the Viking Formation at 713.2 m of the B. A. Juckniess 13-15 well (Lsd 13-15-22-23W3) are thought to represent sand injection into syneresis cracks (White, 1961; Burst, 1965).

Microfaults are widespread, but are most extensive in type-II and thin type-IV elements of the Spinney Hill Sandstone, as well as in type-II ferruginous concretions with siderite. The throw of such fractures is usually 25 mm or less. Comparable features are figured by Reineck (1967, Figs. 24 and 25), from sediments of the North Sea. Microfaults occasionally transect phosphate nodules in the Joli Fou Formation. Normal faults with throws in the range of 1 m to 10 m or more are fairly common in the Lower Colorado (see also Evans, 1970, p. 485).

Mudstone Flakes

Pebble and cobble-grade mudstone and siltstone flakes of local derivation are frequently abundant. Some occur in tabular cross-laminae, together with abundant chert pebbles and granules as conglomeratic intercalations in fine to coarse-grained quartzose sandstone at the base of the Joli Fou Formation, for example, in the Imperial HB Furness No. 1 well (Lsd 8-7-48-27W3) at 525.6 m (Pl. XIV, Fig. 1). They indicate erosion of the uppermost mudstones and siltstones of the Mannville strata immediately prior to Joli Fou sedimentation. Dark grey mudstone and moderate olive brown ferruginous mudstone and siltstone flakes are occasionally found in Viking type-III, IV and V elements in the Kindersley-Kerrobert district, e.g. the Canus Amoco Ulster Teo 6-2-29-24 well (Lsd 6-2-29-24W3) from 710.2 to 711.3 m.

The coccolithic micrite flakes of the Second White-Speckled and uppermost Big River shales are predominantly bladed and tabular and range in grade from fine silt or less to pebble size. Their thicknesses, however, are frequently 0.2 mm and less. The flakes generally display well rounded outlines, are organized into oriented laminar aggregates up to 1 mm or so thick, and are separated by dark grey, bituminous mudstones similar in thickness. Successive laminar aggregates may exhibit marked differences in the size of constituent flakes, such that aggregates comprising pebbles and granules are succeeded by aggregates of sand and silt or even finer particles (Pl. XIV, Fig. 2). These features are particularly well displayed near the base of the Second White-Speckled Shale (376 m) in the core of the Duval Saskatoon 6-18-36-6 well (Lsd 6-18-36-6W3). It is suggested that each laminar aggregate originated as a thin skin of coccolithic material, continuous over wide areas of the sea floor and made cohesive early in diagenesis. This skin was eroded by weak currents and subjected to limited transportation prior to being redeposited as rounded flakes. Possibly the coccolithic skin was rendered susceptible to current erosion by the development of syneresis cracks (White, 1961).

Structures in Bentonites

Bentonites and bentonitic mudstones (Pl. XIV, Figs. 3 to 5) occur throughout the Lower Colorado and are associated with type-I and type-II and less commonly with type-III elements. Some beds are up to 60 cm thick, especially in the Viking Formation of the Kindersley-Kerrobert district, where three main bentonite beds are important for local correlations. Their lower contacts are invariably sharp, whereas the upper generally grade into the overlying lithology, mostly a detrital mudstone. The gradation is typically seen as a progressive increase in medium dark grey, detrital mudstone laminae, intercalated with very light grey bentonite as concordant groups within sets and as superposed sets of cross-laminae; e.g. 717.8 to 718.3 m in the Pennant Smiley Hoosier 7-16-31-27 well (Lsd 7-16-31-27W3). Sharp upper contacts of bentonite layers also occur and these may be planar or irregular, e.g. fine-grained sandstone on bentonite at 681.5 m in the Pennant Teo Coleville 10-34-30-25 well (Lsd 10-34-30-25W3). Wedging out is also occasionally seen in cores, as in the case of a 25 mm thick layer of the Big River Formation at about 701.2 m in the Oliphant NWRCo Gorefield 6-12-25-27 well (Lsd 6-12-25-27W3).

In general, each bentonitic mudstone layer, comprising a pure bentonite grading upward into detrital mudstone with subordinate bentonite, is a coset of cross-laminae. Each set consists of tabular laminae, angular or concordant with respect to a usually planar bounding surface, which in turn truncates underlying laminae at low angles. Horizontal and gently inclined laminae may also occur, though these appear to be largely restricted to bentonites a number of centimetres in thickness only.

Type-III bentonites frequently display gradational boundaries and contain large admixtures of sand and detrital mud, as a consequence of burrowing. Mudstone partings in the superjacent bioturbated sandstones frequently contain a high proportion of bentonite, as judged by their lighter colour compared with partings higher in the sandstone. In type-I and type-II elements also, contamination of bentonites with detrital mud, usually from the superposed layer, is a result of downward burrowing and filling; e.g. in the Viking at 733.5 m in the Husky Dome Whiteside 1-15 well (Lsd 1-15-30-16W3), where *Teichichnus* is well preserved (Pl. XIV, Figs. 3 and 4), and at 747.8 m in the Canadian Seaboard Fusilier 7-1-33-27 well (Lsd 7-1-33-27W3), where interconnected tubes similar to *Chondrites* occur.

Bioturbated Sediments

Variably, though often poorly sorted, fine to coarse-grained sandstone and sandy siltstone layers with varying proportions of scattered granules and pebbles, as well as incorporated mudstone in the form of irregular, intermittent partings and continuous intercalations, constitute the type-III elements of the sequence. These are characterized by general absence of recognizable primary sedimentary structures, save for minor, usually scarce intercalations of well sorted, laminated sandstone or silty mudstone. On the other hand, these elements display great abundance of well developed biogenic structures (Pl. XV), to the extent that inclined biogenic laminae similar to those of trough cross-stratification (Pl. XV, Figs. 2, 3 and 4) frequently form superposed sets (Pl. XV, Figs. 5 and 6). The widespread occurrence of burrow forms throughout type-III elements and the occasional vestiges of primary structures suggest that the general absence of current-formed features may be attributed to animal activity below the sediment-water interface. Type-III elements are a metre or so thick in the Pense Formation, but rarely exceed 30 cm in the "Pense-like" facies of the lowermost Joli Fou (Maycock, 1967). These elements are best developed in the Viking Formation in the south of the study area (cf. Jones, 1961a, b), where they may constitute the greater part of the formation, reaching thicknesses of 6 to 9 m. Type-III elements also make up an important part of the St. Walburg Sandstone.

Viking type-III elements frequently, though not invariably, display a downward decrease in grain size, sometimes from coarse to medium to very fine-grained sandstone or sandy siltstone, but often entirely within the fine sand grade. This gradation may be accompanied by decrease in the proportion of granules and pebbles, and by increase in the proportion of mudstone as sub-horizontal partings, from scarce and discontinuous to more closely spaced, interconnected networks and continuous intercalations. By this passage some type-III elements grade into type-II alternations of mudstone and fine-grained sandstone. From such considerations it seems likely that type-III elements initially, and at least in part, arise through biogenic disruption of sandy type-II.

The type-III elements of the lowermost Joli Fou contain numerous partings and continuous intercalations of frequently laminated silty mudstone, separating irregular lenses and composite layers of fine-grained sandstone, which latter often display pendulous distensions of the lower surface. Vestigial primary lamination is commonly seen in the more continuous sandstone layers. In these elements, as in the Viking, the described downward decrease in size and concomitant increase in mud is fairly common as is the passage from type-III to type-II elements. In the St. Walburg sequence, bioturbated units comprise poorly consolidated fine to medium-grained sandstones with numerous closely spaced, interconnected mudstone partings.

Concretionary Layers

Ferruginous concretions with siderite are widespread, associated with sediments representing all five sequence elements throughout the study area and occur in all stratigraphic units. In thickness they rarely exceed 30 cm and are commonly less than 15 cm. In type-I and type-II elements, concretionary layers are frequently separated by beds a metre or more thick; e.g. the Big River Formation from 698.6 to 709 m in the Kewanee Kindersley 6-14 well (Lsd 6-14-29-24W3). Each concretion is made up of a microcrystalline core, in which primary sedimentary structures are to a large extent obscured or even obliterated, flanked by transition zones, where original detail is often well preserved. Frequently scoured surfaces (Pl. XVI, Fig. 1), coquinoidal layers (Pl. XIX, Fig. 6) and laminated siltstone and fine-grained sandstone (Pl. VII, Fig. 1; Pl. XVII, Fig. 2) serve as sites of concretionary development. Sideritic spherulites and pyrite replacements of these are largely confined to the concretionary cores (Pl. XVI, Figs. 2 to 4). Boundaries with enclosing sediments are either transitional or sharp. In the latter instance, the boundary may be relatively even, as in the case of a 12.5 cm layer at 720.2 m in the Viking Formation of the Pennant Brock East 11-22-28-19 well (Lsd 11-22-28-19W3), or it may exhibit polygonal patterns of depressions reflecting ridges of the sub and superjacent mudstone surfaces, as in the Big River Formation at 712.8 m of the Pennant Smiley Hoosier 7-16 well (Lsd 7-16-31-27W3). Where concretionary growth is uneven and at right angles to the primary bedding, the resulting distension of the boundary with the enclosing rock, as at 645.6 m in the Viking Formation of the Mosbacher CHCTV Cactus 10-11-36-26 well (Lsd 10-11-36-26W3), may give rise to gentle warping of the enclosing laminae (Pl. XVII, Fig. 1).

Similar concretions also occur in type-III, IV and V Viking and Spinney Hill elements, especially in the southern part of the area, where they form concordant layers of microcrystalline siderite a few centimetres in thickness, and as beds of strongly indurated sandstone and conglomerate, 30 to 60 cm thick. An example of the first type is provided by layers of ferruginous siltstone in cross-laminated glauconitic subarkose of the Spinney Hill Sandstone at 698.8 m in the Ceepee Daniels 6-29 well (Lsd 6-29-31-19W3), and the second by the interval 726.2 to 726.6 m in the Viking Formation of the RGAE 1-4 Eureka 1-4-32-23 well (Lsd 1-4-32-23W3). The latter lies at the relatively coarse-grained top of a bioturbated muddy fine-grained sandstone and this mode of occurrence is typical for type-III and type-IV elements. However, individual sandstone units may also exhibit strong cementation at intervals of a metre, as from 684 to 687.6 m in the Viking Formation of the Altair Clark GE Dods 6-14-31-22 well (Lsd 6-14-31-22W3).

Aggregates of pyrite crystals are widely distributed throughout the Lower Colorado strata, especially where it is sandier. They vary from scattered accessory amounts, through major cement, to the dominant component. Pyrite tends to be concentrated at lithologic discontinuities and frequently occurs at the erosional interfaces of fine-grained sandstones in type-I and type-II elements. It forms isolated crystal aggregates and both intermittent and continuous stratiform concretions, often evenly encrusting irregularities of a given interface, such as current markings and burrow infillings (Pl. XVII, Figs. 3 and 4). Spherical aggregates of pyrite crystals are found in some bentonite layers (Pl. XIV, Fig. 5). Primary bedding features, notably horizontal lamination and cross-stratification, are frequently preserved where entire type-I and type-II sandstone layers have been impregnated with pyrite. Advanced stages of stratiform pyrite are represented by internal differentiation into a microcrystalline core and a more coarsely crystalline peripheral zone with a mammillated outer surface. Nodular pyrite is likewise located where there is lithologic heterogeneity, and in type-III elements of the Viking Formation it is frequently associated with *Teichichnus*, as from 744.9 to 749.5 m in the Imperial Athenian 16-22-24-22 well (Lsd 16-22-24-22W3). Horizontal pyrite-filled tubes in mudstones, 10 cm or so long and up to 15 mm in diameter and frequently incorporating chert pebbles and fish teeth, are interpreted as pyrite-impregnated burrow systems. Primary laminae frequently bend around pyrite nodules (Pl. XVII, Fig. 5), suggesting that the latter were present prior to compaction of the sediment.

Nodules

Phosphatic nodules appear to be largely restricted to the Joli Fou Formation and occur singly or as aggregates, presumably *in situ*, within type-I elements. They are also incorporated into fine-grained type-II glauconitic sandstones, along with other indigenous material, such as fish remains and pelecypod debris. Most nodules are made up of closely packed, unorganized, spherical or ellipsoidal bodies with random, microcrystalline structure, (Pl. XVIII, Fig. 1). In some cases they incorporate discrete phosphatic bodies and grains of silt and fine sand size arranged in horizontal laminae as well as in ripple-drift cross-laminae on a scoured surface (Pl. XVIII, Fig. 2). Possibly the bodies forming these laminae reflect phosphatization of clay floccules, moved by traction currents. Phosphatic nodules frequently exhibit concentric nodular lamination, particularly near the periphery. Redeposited phosphatic nodules were observed at 472.3 m in the Duval Saskatoon 6-18-36-6 well (Lsd 6-18-36-6W3), at 463.3 m in the Midas No. 3 well (Lsd 14-28-36-6W3) and at 689.2 m in the Ceepee Daniels 6-29 well (Lsd 6-29-31-19W3).

Repetitive Layering

The elements making up the Spinney Hill Sandstone and the Viking Formation, are frequently characterized by preferred vertical order of appearance in sets, which latter in turn may exhibit repetition in vertical sequence. Those of the Spinney Hill display vertical passage from clay to coarse sand-grades; those of the Viking Formation from clay to pebble and even cobble-grades. In the latter, each set of sequence elements increases upward in grain size, whereas the reverse is true for the former.

Coarsening-upwards sets of sequence elements in the Viking occur in the modal association II-III, with I-II-III-IV-V as the composite association (terminology modified after Duff and Walton, 1962). North of the Dodsland-Hoosier production trend, the formation undergoes pronounced reduction in grain size and thickness, so that vertical repetition of sequence elements is restricted and cannot be described as cyclical. However, farther south in the proximal shelf region, where a wide range of sediment size grades is encountered, sequence elements are clearly defined as is cyclic repetition of elements. Electric well logs, particularly the resistivity, indicate that cyclicity becomes more pronounced to the south and southwestwards in Saskatchewan and Alberta.

The Spinney Hill Sandstone is characterized by fining-upwards sets of sequence elements, with III-II making up the modal association and IV-III-II-I the composite association. The type-IV elements may reach a metre or so in thickness and commonly rest upon an erosion surface. These elements become thicker and more numerous at the expense of type-I elements to the north in the proximal fluviomarine sequence, where the sand content and thickness of the unit as a whole increase.

Fluid-flow Characteristics

The scheme of sequence elements provides a systematic approach to the description of reservoir properties. This is shown to greatest advantage in the Viking cores (Table 1). Stratification features, impermeable or only slightly permeable to flow, are fairly numerous. They constitute potential or actual reservoir seals, and account for heterogeneities within lithologies of good reservoir quality. These discontinuities are primary, (1), consisting largely of mudstone and bentonite intercalations, and secondary, (2), reflecting uneven distribution of cement:

(1) Detrital mudstone is the main component of type-I and fine grained type-II elements of the Viking Formation, and gives rise to significant breaks in production potential of sandy type-II elements and, more importantly, type-III, IV and V elements. Nearshore type-IV elements and coarse-grained type-III proximal shelf elements of the Dodsland-Hoosier production trend to the immediate south and southeast, contain comparatively few continuous mudstone intercalations. Those which do occur range up to 10 cm thick, and most frequently are less than 3 cm thick. Mudstone intercalations are also common in some type-V elements, notably in the pebbly diamictites ("Viking chert") at and near the base of

the formation in the Smiley-Dewar district. The other main type of primary reservoir discontinuity is provided by thin bentonites and bentonitic mudstones, present at two main levels in the formation (Jones, 1961a; Evans, 1970).

(2) The most common reservoir seals and discontinuities of secondary origin are local calcite and siderite cemented, well indurated conglomerate and sandstone. These occur in the coarse-grained upper parts of type-III elements and are here and there repeated in the "multistory" type-III elements of the Dodsland-Hoosier trend. Some well sorted nearshore sandstones at the top of the Viking in the Bayhurst district likewise display a high degree of induration. Massive, stratiform pyrite also might be of local importance as reservoir seals. Similar features are recorded by Christopher (1966, p. 204) from the top of the Shaunavon Formation of southwestern Saskatchewan.

The four principal reservoir lithologies in the Viking occur as sandy type-II and type-III, IV and V elements:

(1) The horizontal permeability of type-II elements is generally less than 10 mD. However, that in relatively well sorted, usually fine-grained sandstone layers, 6 cm or more thick, may be up to several hundred millidarcies, though less than 100 mD is most common. Because of the abundant mudstone intercalations, vertical permeability, by comparison, is considerably reduced. Porosities of type-II elements are generally in the range 15 to 25 per cent, with the higher values tending to occur in the upper parts where succeeded by type-III elements.

(2) Type-III elements in general exhibit a wider range of horizontal permeability, such that the latter may range up to one darcy or more in the coarse-grained upper parts and down to 10 mD and as low as 0.01 mD in the correspondingly finer grained and argillaceous lower parts. As in type-II elements, vertical permeability is markedly lower than horizontal permeability, though here high vertical permeability tends to characterize the upper parts of elements. Porosity is mostly in the range 20 to 30 per cent.

(3) Highest permeability and porosity occur in type-IV elements, where horizontal permeability ranges from several hundred millidarcies to 1.5 D and porosity from 30 to 35 per cent. Again, vertical permeability is usually lower than horizontal permeability, except for a few places where vertical permeability exceeded 2 D and the horizontal.

(4) Type-V elements, such as in the "Viking chert" have a horizontal permeability of up to several hundred millidarcies and porosity of the order of 30 per cent.

The coarsening upward order of the Viking sequence elements thus defines gradations of permeability and porosity, so that in general, higher values are obtained near the top and lower values toward the base. As noted above, however, strongly cemented layers, often localized in the relatively well sorted parts of elements, are responsible for abrupt departures from this relationship. Furthermore, since variation in fluid-flow characteristics may be expressed in terms of associations of sequence elements, the progressive nearshore to distal-shelf change in the nature of the associations and concomitant decrease in modal grain size takes on considerable importance as an exploration tool. It is possible that maximum horizontal permeability in type-IV elements of the nearshore deposits is parallel to the direction of maximum inclination of cross-stratification, as noted in other sequences by Montadert (1963) and Hewitt and Morgan (1965). In absence of oriented cores, the inclination of cross-stratification in the type-IV elements is not known. However, it is likely that palaeocurrent directions defined by cross-stratification are parallel to the trend of sand bodies (Campbell, 1971). Likewise, the inclination of mudstone intercalations may be logged from continuous dipmeter surveys (Gilreath and Maricelli, 1964) and provide information relating to the direction of maximum horizontal permeability.

SEQUENCE ELEMENT \ LOCATION IN MARINE BASIN	NEARSHORE DEPOSITS	PROXIMAL SHELF DEPOSITS	DISTAL SHELF DEPOSITS
V good reservoir quality; incorporate strongly indurated layers (calcite, siderite, pyrite cements) and mudstone intercalations as reservoir heterogeneities	scarce; material coarser than sand usually concentrated in thin layers making up minor proportions of other elements	abundant; highest permeabilities (several hundred md) in diamictites belonging to lower parts of clinobeds[2]; primary and secondary heterogeneities very numerous	absent; material coarser than sand occurs as scattered clasts or as thin layers within other elements
IV good reservoir quality; strongly indurated layers (calcite, siderite cements) mudstone intercalations, ripple-drift cross-laminated sandstones are permeability barriers	abundant, planar foresets give rise to highest horizontal permeabilities (several hundred md to >2 D) especially near top of sequence[1]; porosities in range 25 to 35 per cent; primary heterogeneities more numerous downward; secondary heterogeneities at top of sequence	scarce; occur in upper part of sequence where present	very scarce, though well sorted fine-grained sandstone layers may make up minor proportions of type-II and-III elements
III reservoir quality good to poor; strongly indurated parts (calcite, siderite, pyrite cements) and continuous mudstone intercalations are permeability barriers	relatively scarce; usually found near base of sequence, proportion of mudstone intercalations increases downward	abundant; variable horizontal permeability (<0.01 md to several hundred md); porosities in range 20 to 30 per cent form coarsening-upward units in upper parts of clinobeds[3]; primary heterogeneities in lower parts; secondary heterogeneities near element tops	common; high mud content, variable but usually low horizontal permeability (<0.01 md to several tens of md)[4] porosities in range 15 to 25 per cent
II reservoir quality fairly good to poor, incorporate stratiform and nodular pyrite concretions, sideritic concretions and contain numerous mudstone layers	scarce, occur near base of sequence	abundant; variable horizontal permeability (<0.01 md to several hundred md); porosities in range 15 to 25 per cent; form lower parts of clinobeds[3]; downward increase in mud content	common in lower part of sequence[4]
I reservoir heterogeneities, seat and cap rocks	very scarce	common; occur near top of succession and as intercalations	abundant; occur near top of succession and as intercalations

[1] main producing lithology of Bayhurst natural gas field

[2] Smiley-Dewar "Viking chert" oil reservoir

[3] crude oil and natural gas reservoirs of the Dodsland-Hoosier "Viking sand" production trend, Brock, Glidden, Greenan, Plato, Totnes

[4] Unity natural gas reservoir

Table 1 — Sequence elements, depositional environments and generalized fluid-flow characteristics, Viking Formation, west-central Saskatchewan.

Large-scale, Composite, Inclined Stratification

Large-scale, inclined stratification, which may be detected only through detailed correlation of wells in areas of closely spaced control points, is recognized by Reasoner and Hunt (1954a) in an electric-log cross-section through the Smiley-Dewar field within the Dodsland-Hoosier production trend. Imbricating relationships of successive lithologic units making up the Viking Formation of the Dodsland-Hoosier trend as a whole is elaborated by Evans (1970). This interpretation is also favoured in the present account and is to a large extent substantiated by study of internal sedimentary structures. This feature is termed large-scale, composite, inclined stratification in accordance with the nomenclature of Gradzinski (1970) for inclined units, themselves at least in part made up of sets of inclined strata. Since the "members" recognized by Evans (1970) are for the most part not distinctive in terms of lithology and are recognized chiefly on the basis of their position in vertical sequence, they are termed clinobeds (after Rich, 1951) in the present account.

Recognition of clinobeds is facilitated in the Dodsland-Hoosier production trend by two prominent layers of bentonite and bentonitic mudstone, here named the upper and lower bentonites respectively, and by the widely developed coarsening-upward nature of the clinobeds themselves. Thus Evans (*loc. cit.*, Fig. 3, p. 472, 473) distinguishes five main units in a NNW-SSE cross-section drawn from North Eureka to Avon Hill. In Fig. 33 of the present account this line of section is extended northwestward to Buffalo Coulee. The upper bentonite reaches a thickness of 60 cm — 1 m and is located at the top of the lower, sandy part of the Viking Formation. The lower bentonite is of similar thickness, but marks the upper boundary of the Smiley clinobed ("O" and "N" Members of Evans) and is not distinguished beyond the southern pinchout of this lowermost Viking unit. The succeeding Hoosier ("M"), Crystal (Lower "L"), St. Eloi (Upper "L") and Merrington ("K") clinobeds are distinguished on the basis of lithology. In each case, northerly sandy or muddy type-II elements are replaced southward with increase in overall thickness of the clinobed by type-III elements, often with scattered pebbles near the top, passing downward into sandy then muddy type-II elements and southward into thin muddy type-III or type-II elements. Locally, as in the Dodsland area, separation of the Crystal and St. Eloi clinobeds depends upon recognition of the multistory nature of type-III or sandy type-II elements, defined by local induration at the base of repetition in upward coarsening above the Crystal clinobed.

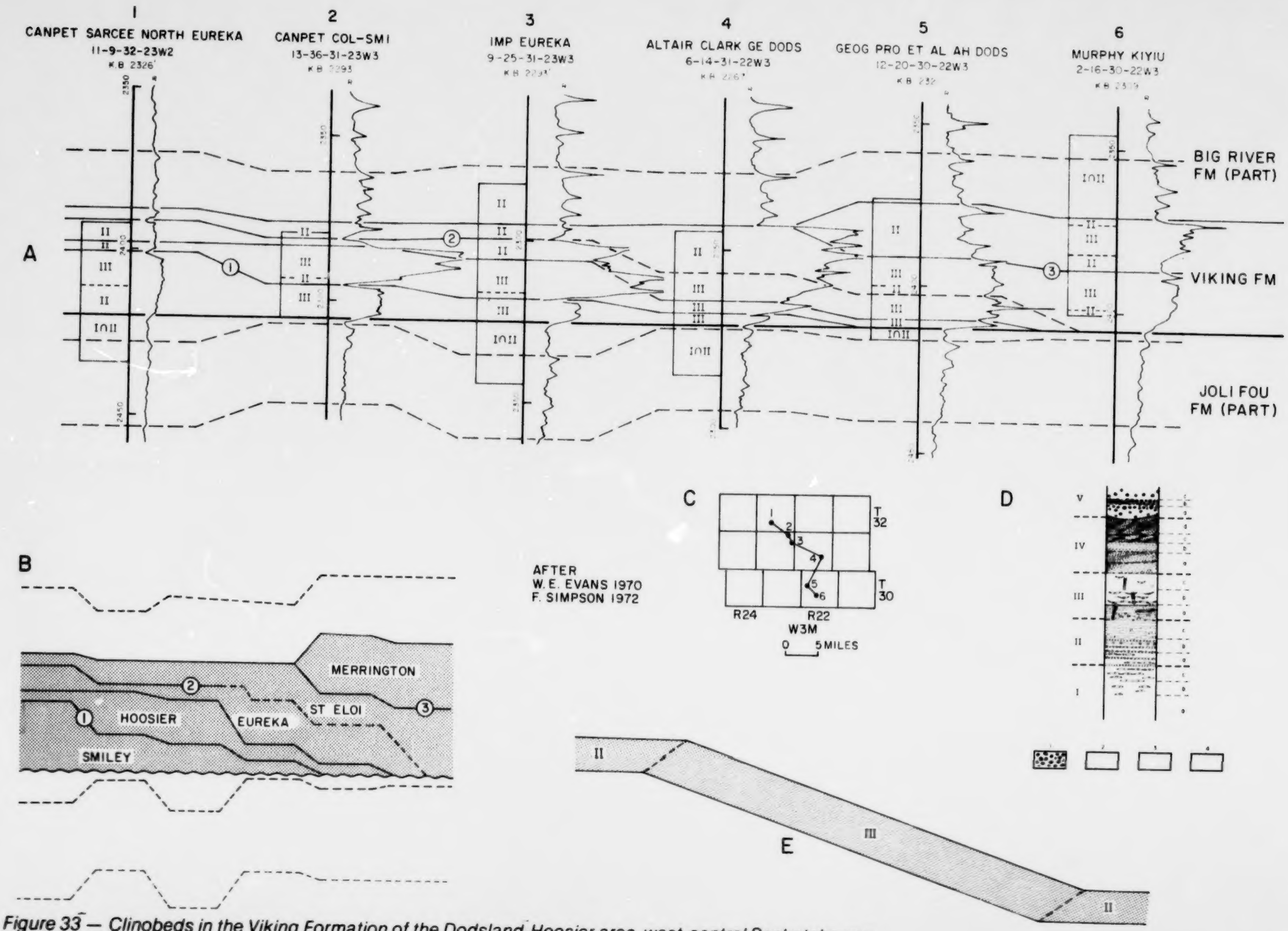

A
1
CANPET SARCEE NORTH EUREKA
11-9-32-23W2
K.B 2326'
2
CANPET COL-SMI
13-36-31-23W3
K.B 2293
3
IMP EUREKA
9-25-31-23W3
K.B 2293'
4
ALTAIR CLARK GE DODS
6-14-31-22W3
K.B 2267'
5
GEOG PRO ET AL AH DODS
12-20-30-22W3
K.B 232
6
MURPHY KIYIU
2-16-30-22W3
K.B 2319
BIG RIVER FM (PART)
VIKING FM
JOLI FOU FM (PART)
2350
2400
2450
II
III
I∩II
①
②
③
B
MERRINGTON
ST ELOI
EUREKA
HOOSIER
SMILEY
AFTER
W. E. EVANS 1970
F. SIMPSON 1972
C
T 32
T 30
R24
R22
W3M
0 5 MILES
D
V
IV
III
II
I
E
II
III

Figure 33 — Clinobeds in the Viking Formation of the Dodsland-Hoosier area, west-central Saskatchewan.
A — Sequence elements in clinobeds.
B — Designations of inclined strata, delimited by bentonites 1, 2 and 3 and by lithologic change.
C — Location map.
D — Sequence elements I to V; 1 — gravel, 2 — sand, 3 — silt, 4 — clay.
E — Internal structure of a clinobed.

Skeletal Remains and Trace Fossils

Palaeoecology

Faunal assemblages of the Lower Colorado display both boreal and gulfian affinities, but are deficient with regard to numbers of taxa and individuals representing each major group, by comparison with equivalent assemblages elsewhere in the world (Reeside, 1957). Groups poorly represented, if at all, include sponges, bryozoans, echinoderms, brachiopods and belemnoids. On the other hand, foraminifers, pelecypods and ammonoids are generally of wide distribution and may be locally abundant. In west-central Saskatchewan, body fossils, exclusive of micro-fossils, are largely restricted to the transgressive lower Joli Fou and the upper Big River strata respectively. Maximum diversity is exhibited by the Joli Fou faunal assemblages and tends to occur in association with green and subordinate drab fine-grained sandstone in mudstone. The Big River assemblages reflect the onset of environmental conditions repeated up to the end of Colorado deposition. The regressive strata are poorly fossiliferous, but provide a rich and instructive record of trace fossils and bioturbation.

Molluscs constitute the most widely distributed group of macro-invertebrates. Of these, pelecypods are the most common, though it is important to note that in part this is due to the fact that the cores taken represent a strong sampling bias in favour of sandy facies. *Inoceramus*, associated with *Ostrea*, *Nuculana* and *Exogyra*?, is common as disarticulated valves and shell fragments throughout the lower part of the Joli Fou Formation. Again, *Inoceramus* is abundant in the upper Big River strata and also in the lowermost mudstones of the Upper Colorado Subgroup where the only other pelecypods recorded are relatively scarce, flattened valves of *Callistina*. Gastropods were seen as several indeterminate moulds in the Joli Fou and one in the Viking Formation at 622.6 m in the Tidewater Saltburn Crown No. 1 well (Lsd 4-18-23-16W3). Scarce, smooth shells of a scaphopod, possibly *Fustiaria*, were found in the Joli Fou Formation. The only ammonites found were scarce aptychi in the Joli Fou and scarce, flattened, indeterminate moulds in the Big River Formation. They appear to be fairly common in the overlying Upper Colorado sediments, since only cursory examination revealed several flattened moulds of *Watinoceras* (Pl. XIX, Fig. 1) in the Duval Saskatoon 6-18-36-6 well (Lsd 6-18-36-6W3).

Brachiopods are restricted to Joli Fou green beds, where lingulid and disciniscid forms are found poorly preserved in type-II sandstones. The lingulids occur as fragments in the bedding plane of laminated, fine-grained sandstones and are associated with *Inoceramus* debris. They are also encountered in redeposited sandstone clasts of intraformational conglomerates. Since these lingulids have clearly undergone transportation, they offer no insight into depositional conditions. However, they may have been eroded from enclosing muds, in which case the habitat was probably below the prevailing depth of wave action (Paine, 1970). The disciniscids, though locally abundant, likewise occur in current-deposited aggregates.

Complete or nearly complete ophiuroids, are restricted to type-II fine green sandstones in the lower Joli Fou (Pl. XIX, Figs. 2 to 5), and at 693.1 m in the Ceepee Daniels 6-29 well (Lsd 6-29-31-19W3). Separate arms made up of fused ambulacrae also occur at erosional interfaces and are current aligned (defined by tool and scour markings) as at 682.4 m in the Ceepee Dukesbury 13-18 well (Lsd 13-18-34-21W3). More commonly, ossicles are found at interfaces, either singly or in concentrations infilling shallow scour markings, as at 683.1 m in the Ceepee Dukesbury 13-18 well. Good preservation of ophiuroid specimens suggest that transportation was minimal. Ophiuroids frequently comprise dense swarms occupying parts of the sea bottom, so that the entire surface is swept by their arms (Thorson, 1959). It is likely, then, that much of the burrowing in type-II elements and the more extensive bioturbation of type-III elements in the Spinney Hill Sands resulted from the activities of ophiuroids.

Cyclostomate bryozoans are known from two occurrences of fragmented networks near the base of the Joli Fou Formation; at 287.4 m in the Banff Aquit Lepine Lake 1-25-62-25 well (Lsd 1-25-62-25W3) and at 681.5 m in the Ceepee Dukesbury 13-18 well. In the former instance, bryozoan fragments occur in mudstone, associated with ostracode carapaces and *Inoceramus* debris; in the latter, at the erosional interface basal to a coquinoidal layer, and are associated with fragments of *Inoceramus* and *Ostrea*, as well as abundant Ostracoda and Foraminifera. Bryozoans favour environments of agitated water and slow deposition (Schopf, 1969) and in the unstable sand and mud bottom conditions of the Lower Colorado sea, substrates were probably molluscan valves and seaweeds. Although their good preservation suggests only small displacement by currents and rapid burial, little may be deduced about the environment of deposition from the small amount of material. However, it is noteworthy that bryozoan material and abundant microfossils were recorded by Lagaaij and Kopstein (1964) from the base of the fluviomarine offlap sequence of the Rhone delta.

Foraminifera of the Joli Fou Formation constitute a largely agglutinating assemblage (*Haplophragmoides gigas* microfauna), such that the lower part of the Formation is characterized by species of *Ammobaculites*, *Ammobaculoides*, *Ammomarginulina*, *Haplophragmoides* and *Saccammina* and the upper part by species of *Flabellammina*, *Glomospira*, *Miliammina*, *Psamminopelta* and *Reophax* species, with the pelagic *Hedbergella* also appearing in the upper part (Guliov, 1967). Forms occurring throughout the Joli Fou include *Ammobaculites, Ammobaculoides, Ammomarginulina, Bathysiphon, Gaudryina, Haplophragmoides, Hippocrepina, Saccammina, Trochammina* and *Uvigerinammina* (Guliov, *loc. cit.*). Affinities with the Gulf Coast faunal province are indicated by *Dorothia, Pullenia* (Edwards, 1960) and *Ammodiscus kiowensis* (Guliov, *loc. cit.*). The interval between the top of the Viking Formation and the base of the Fish-Scale Marker is characterized entirely by an agglutinating assemblage of Foraminifera in the Alberta foothills (Wall, 1967) while in Manitoba (Wickenden, 1945), the *Miliammina manitobensis* microfauna recorded by Wall (*loc. cit.*) comprises *Ammobaculites, Gaudryina, Haplophragmoides, Milliammina, Uvigerinammina* and *Verneuilina*. The top of the Big River Formation also contains agglutinating forms exclusively (*Verneuilinoides kansasensis* microfauna) represented by *Ammobaculites, Gaudryina, Haplophragmoides, Miliammina, Trochammina* and *Verneuilinoides* (Park, 1965; Wall, *loc. cit.*; Huffman, 1969). The Second White-Speckled Shale is characterized by an entirely pelagic microfauna (Wall and Germundson, 1963; Park, 1965; Caldwell and North, 1966; Huffman, 1969). Thus, on the basis of Foraminifera, the first transgressive phase is considered to have provided a shallow-water, marine environment with cool temperatures and subnormal salinities (Guliov, *loc. cit.*) as did the early stages of the second transgressive phase (Wall, *loc. cit.*).

Coccoliths are sporadic near the top of the Big River Formation and attain importance in the carbonate layers intercalated with the frequently bituminous mudstones of the Upper Colorado. The coccolithic material is associated with abundant *Inoceramus* debris, fish remains, ammonites and pelagic Foraminifera. The alternations of coccolith-rich calcareous layers and bituminous mudstone are analogous to the Holocene sediments of the Black Sea, described by Muller and Blaschke (1969) and Bukry *et al.*, (1970). Bathurst (1971) concludes that most coccoliths were deposited either as faecal material or in the digestive tracts of dead animals.

Trace fossils constitute the only indisputable record of autochthonous life in the Lower Colorado. They occur in the mudstones and siltstones of the transgressive units for the most part as frequently flattened tubes and networks and may be observed in planes parallel to the bedding, which latter frequently intersects them in the more fissile mudstones. Where thin layers of sand, granules and small pebbles together with fish skeletal debris and pelecypod fragments occur in type-I elements, these components are also often organized in sub-horizontal flattened tubes. The greatest profusion of trace fossils is found within the regressive type-II sands, particularly the Viking, which in addition exhibit numerous recognizable burrow morphologies. These are internal structures, formed near the depositional interface during or immediately after deposition of the enclosing sediment. Syn- and post-depositional burrow systems also characterize sandstones with lamination not destroyed by bioturbation and, where these layers rest upon mudstone, there are frequent occurrences of current-excavated, pre-depositional burrows. They are preserved on sandstone soles as sand-filled, positive hyporeliefs (see Seilacher, 1964), which reflect burrowing in the muds prior to sand deposition. In the majority of cases, the identity of the trace-forming organism remains unknown. However, similarities between burrows (*Thalassinoides*) in the Viking Formation, and those made by Recent decapods are such that a common origin may be considered likely. Other structures may have been formed by burrowing crustaceans, pelecypods, polychaete worms and ophiuroids.

Vertebrate remains are widely distributed and they are represented by broken and disarticulated skeletal material of fish. Ganoid, ctenoid and cycloid scales, frequently broken, as well as small bones, abraded teeth and separate vertebrae, sometimes occurring with small rounded bodies which may be otoliths, are the most common. These are found both as randomly distributed, scarce particles in all of the principal Lower Colorado sediments, and as a major clastic component of some sedimentary layers, ranging from laminar grain aggregates to units 10 cm or so thick. The relatively high concentrations of fish debris are usually associated with only minor amounts of other organic material, principally *Inoceramus* fragments.

Severe limitations are imposed upon attempts to understand the Lower Colorado biota in terms of bottom communities by (1) the fragmental character of fossils preserved in assemblages concentrated by currents, (2) the incomplete nature of the fossil record evidenced by extensive bioturbation and numerous trace fossils in fossil-poor sequences.

The scheme of five principal ("first-order") biofacies types (Table 2), elaborated by Schafer (1962, 1963) on the basis of research in the North Sea, places emphasis on gross lithology and bedding types, as well as animal hard parts and soft-sediment deformations of organic origin. It presents an interpretative framework for the analysis of fossil assemblages in marine deposits. Table 3 outlines the main associations of biofacies in the Colorado of Saskatchewan and relates these to depositional environments. The Joli Fou and Big River Formations, are characterized by vital-isostrate biofacies. Below the Fish-Scale Marker, these are replaced westward and eastward by predominantly vital-heterostrate types in sandy units reflecting

DIAGNOSTIC FEATURE / BIOFACIES	FAUNAL ASSEMBLAGES	BIOSTRATINOMY	BIOGENIC STRUCTURES	PRIMARY STRATIFICATION TYPES	GROSS LITHOLOGY
VITAL-NONSTRATE (VITAL-ASTRATE)	LIFE ASSEMBLAGES (CONTINUOUS, AUTOCHTHONOUS BIOCOENOSES)	COMPLETE SKELETONS OF BENTHOS IN LIFE POSITION	BURROWS (ALL TYPES POSSIBLE, BUT MAINLY FODINICHNIA AND DOMICHNIA) AND BORINGS	STRATIFICATION FREQUENTLY ABSENT	BIOHERMAL AND BIOSTROMAL DEPOSITS; HOMOGENEOUS FINE-GRAINED DEPOSITS
VITAL-HETEROSTRATE (VITAL-LIPOSTRATE)	LIFE ASSEMBLAGES (PARTIALLY REWORKED, ORIGINAL BIOCOENOSES) AND DEATH ASSEMBLAGES	INDIGENOUS AND EXOTIC SKELETAL DEBRIS IN CURRENT-FORMED AGGREGATES, SOME BENTHOS IN LIFE POSITION	BURROWS (MOSTLY FODINICHNIA, DOMICHNIA AND REPICHNIA)	CROSS-STRATIFICATION (LENTICULAR, WAVY AND FLASER BEDDING; FORESET BEDDING) WITH EROSIONAL LOWER SURFACES OF SETS AND COSETS	SAND; INTERCALATED SAND/SILT AND MUD
LETHAL-HETEROSTRATE (LETHAL-LIPOSTRATE)	DEATH ASSEMBLAGES (INCLUDE RICH TAPHOCOENOSES FROM NEKTON AND PLANKTON), NO INDIGENOUS BENTHOS	INDIGENOUS AND EXOTIC SKELETAL DEBRIS IN CURRENT-FORMED AGGREGATES	NO BIOGENIC STRUCTURES	CROSS-STRATIFICATION (FORESET BEDDING, TROUGH CROSS-BEDDING)	RELATIVELY COARSE-GRAINED DEPOSITS WITH SAND GRADES DOMINANT
VITAL-ISOSTRATE (VITAL-PANTOSTRATE	LIFE ASSEMBLAGES AND DEATH ASSEMBLAGES (TAPHOCOENOSES FROM NEKTON AND PLANKTON)	SKELETONS ARTICULATED AND DISARTICULATED, SOME BENTHOS IN LIFE POSITION	BURROWS (MOSTLY FODINICHNIA AND DOMICHNIA), COPROLITES AND BIOTURBATION STRUCTURES	HORIZONTAL AND GENTLY INCLINED STRATIFICATION	INTERCALATED FINE SAND/ COARSE SILT AND MUD
LETHAL-ISOSTRATE (LETHAL-PANTOSTRATE)	DEATH ASSEMBLAGES (TAPHOCOENOSES FROM NEKTON AND PLANKTON), NO INDIGENOUS BENTHOS	SKELETONS ARTICULATED OR DISARTICULATED	NO BIOGENIC DEFORMATION OF STRATA; COPROLITES MAY BE PRESENT	HORIZONTAL STRATIFICATION	PREDOMINANTLY ORGANIC, FINE-GRAINED SEDIMENT

Table 2 — Marine biofacies of Schafer (1962, 1963) and their diagnostic taphonomic and lithologic features.

SITE OF DEPOSITION / PHASE OF DEPOSITION	WESTERN SHELF	BASIN PROPER	EASTERN SHELF
LATE TRANSGRESSIVE PHASE	WHITE-SPECKLED SHALES WITH INTERCALATED NON-CALCAREOUS SHALE UNITS lethal-isostrate biofacies widespread and monotonous		
	incorporating MEDICINE HAT SANDSTONE lethal-heterostrate biofacies (reworked, relict deposits at unit top-climax shelf condition)	subordinate vital-isostrate biofacies	
	BIG RIVER MUDSTONE: vital-isostrate biofacies		
	FISH-SCALE MARKER IN BIG RIVER MUDSTONES intercalated lethal-heterostrate and lethal-isostrate biofacies with upward and northeastward increase in importance of latter		
	BIG RIVER MUDSTONES (Bow Island-Viking and St. Walburg equivalent) vital-isostrate biofacies		ST. WALBURG SANDSTONE vital-heterostrate and subordinate intercalated vital-isostrate biofacies
REGRESSIVE PHASE	VIKING FORMATION vital-heterostrate biofacies: nearshore *Thalassinoides* biofacies proximal-shelf deep-*Teichichnus* biofacies distal-shelf shallow-*Teichichnus - Chondrites* biofacies vital-isostrate biofacies: distal-shelf and basin muds lethal-heterostrate biofacies: *remanié* and exotic debris in reworked relict deposits		FLOTTEN LAKE SAND vital-heterostrate and subordinate intercalated vital-isostrate biofacies
EARLY TRANSGRESSIVE PHASE	JOLI FOU MUDSTONES vital-isostrate with subordinate vital-and lethal-heterostrate biofacies	SPINNEY HILL SANDSTONE vital-heterostrate with subordinate intercalations of vital-isostrate and lethal-heterostrate biofacies in distal fluviomarine facies	
	sporadic distribution of reworked, relict deposits		

Table 3 — First order biofacies (after Schafer, 1962) of the Colorado Group in Saskatchewan related to depositional environment.

deposition on shelves separated by the basin proper. The Viking vital-heterostrate trace fossils permit differentiation of second-order biofacies, taken to typify nearshore, proximal-shelf and distal-shelf environments respectively. The association of lethal-heterostrate and lethal-isostrate biofacies in the Fish-Scale Marker heralds widespread uniformity in lithofacies and biofacies throughout the area in the uppermost Big River and overlying Upper Colorado sequence.

Preservation of Fossils

Inoceramus is for the most part preserved as calcitic prismatic layers of valves and as fragments of prismatic layers in absence of the aragonitic nacreous layer. Moulds after pelecypod valves are occasionally encountered in fine-grained sandstones of the Joli Fou Formation. These occurrences, indicative of late post-burial dissolution of shell material, are scarce, and in general aragonite dissolution appears to have taken place during the pre-burial or early post-burial stages of diagenesis. A further possibility, the importance of which should not be discounted, particularly in type-III elements, is that skeletal aragonite was finely comminuted within sands by burrowers and was thus rendered readily susceptible to recrystallization. Rare shells preserved as powdery calcium carbonate, reminiscent of chalky aragonite, suggest that this mechanism is a definite possibility. There is a general dearth of aragonite in the sequence as a whole, although some remains in scarce scaphopod shells, very rare nautiloids and some pelecypods. Perhaps these reflect rapid burial. One important palaeoecological implication of the postulated aragonite dissolution relates to the absence of calcareous, benthonic Foraminifera from the sequence. Guliov (1967) discounts late post-burial leaching as a reason for the absence of these from the Joli Fou mudstones and concludes that the microfaunas examined by him indicate sub-normal salinities. However, if it is admitted that dissolution of tests belonging to calcareous, benthonic Foraminifera was possible, the probable salinity range is increased accordingly (cf. Walton, 1964).

Remanié fossils in the Colorado succession are of two main types: (1) skeletal debris incorporated within clasts, themselves within conglomerates which are frequently of intraformational type, in sequences representing the early transgressive and regressive phases; (2) much older material, reflecting considerably different environments of deposition and presumably greater distances of transport, found exclusively in conglomerates of the regressive phase.

To the first category belong fragments of *Inoceramus* and *Lingula* within sandstone pebbles and cobbles of the Joli Fou intraformational conglomerates, as well as fish remains and microfossils in phosphate nodules of the Joli Fou and Viking Formations. The second category is represented by phosphate-impregnated wood, occurring as fairly common granules, pebbles and cobbles, in Viking conglomerates. The wood is a gymnosperm, possibly with affinities to *Araucarioxylon* (Pl. II, Figs. 3 and 4). In transverse cross-section, annual rings are distinct and clearly divisible into early and late wood; there is radial flattening of late-wood tracheids. Wood parenchyma cells are arranged in groups parallel to the annual-ring boundaries. Rays are uniseriate and only rarely biseriate.

Nodules of sedimentary apatite, occurring in the early transgressive sediments and as redeposited clasts in the early part of the regressive bed, contain abundant fine organic debris, which includes well preserved radiolarians (Pl. V, Fig. 5) and diatoms. The following identifications were kindly made by J. H. Wall, of the Alberta Research Council.

(i) Phosphorite nodule in Joli Fou mudstones at 726.9 m in Imperial Dewar 7-15-31-16 well (Lsd 7-15-31-16W3).

- Radiolaria
  - Suborder Spumellina
    - Family Staurosphaeridae
      - Genus probably *Stauracontium* (Jurassic-Recent)
- Diatomaceae
  - Order Centrales
    - Circular forms with pores arranged radially, symmetrical about a given point.
  - Order Pennales
    - Fusiform types with pores bilaterally symmetrical and asymmetrical with respect to the axial field.

(ii) Phosphorite nodule in Joli Fou mudstones at 737.6 m in Imperial Dewar 7-23-31-26 well (Lsd 7-23-31-26W3).

- Radiolaria
  - Suborder Spumellina
    - Family Triposphaeridae
      - Genus probably *Triposphaera* (Ordovician-Cretaceous)
    - Family Euchitonidae
      - Genus *Staurodictya* (Jurassic-Recent)
  - Suborder Nasselina
    - Indeterminate

Wall (*pers. comm.*) remarks upon the unusual nature of the occurrence of pennate diatoms in Joli Fou phosphorite since these forms have previously been regarded as post-Mesozoic in age.

Coquinas

Coquinoidal layers, made up of pelecypod debris and subordinate amounts of other skeletal material (Pl. XIX, Fig. 6; Pl. XX), are found in the sediments of both transgressive phases, but are best developed in the green beds of the lower Joli Fou, where they often reach thicknesses of 10 cm. Much more frequently encountered are very thin, intermittent or continuous layers of shell debris, often incorporating scattered foraminiferal tests, ostracode carapaces and skeletal debris of fish and usually the thickness of a single shell, located either within mudstones as discrete intercalations or at the lower surfaces of type-II very thin, very fine and fine-grained sandstone. A small number of shell-layers within type-IV sandstones were observed, but in many of these intermittent mudstone partings below the coquinas showed the sandstone layers to be composite. In many cases, the pelecypod debris is poorly sorted and ranges in size from individual calcite crystals of *Inoceramus*, to entire disarticulated valves. Articulated valves are scarce. The thinnest layers of pelecypod debris, often consist of well sorted calcite prisms.

The Joli Fou sandstone layers associated with coquinoidal layers are interpreted as mostly resulting from short-lived influxes by storm augmented tidal currents. Possibly some of the pelecypod debris is autochthonous and concentrated through selective erosion of the underlying muds. It is also likely, however, that much of the coquina was transported with the sand from shallower water, by analogy with the storm-derived *Hydrobia* layers (Reineck *et al*, 1968). Some of the very thin coquinoidal intercalations with little or no associated sand in the Big River mudstones probably arose in a similar manner.

Whole valves of pelecypods, especially of *Ostrea*, as well as concavo-convex pelecypod fragments of all sizes and ostracode shells, occurring at erosional interfaces, frequently tend to lie flat in the bedding plane with convex surfaces uppermost (Pl. XX, Fig. 1). In this position of hydrodynamic stability, the first-deposited shells offer least resistance to flow (Richter, 1942) though succeeding shells may exhibit diverse orientations. Several occurrences were noted within Joli Fou type-II sandstones of pelecypod valves oriented normal to the bedding and arranged in irregular clusters without particular orientation (Pl. XX, Figs. 2 and 3). These features are analogous to "edgewise coquinas" (Seilacher and Meischner, 1965) and result from strong wave action.

Skeletal Remains of Fish

Occurrences of fish skeletal debris as the main component of laminar grain aggregates (Pl. XXI, Fig. 1), both intercalated with mudstones and at the lower surfaces of type-II sandstone layers, probably reflect concentration by storm currents. In this respect, they are analogous to the coquinoidal layers. The fish remains are frequently broken and worn thereby suggesting the destruction of carcasses by predators or scavengers, and perhaps lateral displacement by currents. The concentrations in part arise through selective erosion of the enclosing muds by currents, so that skeletal debris remains as a lag deposit. The role of benthonic, sediment-eating invertebrates in concentrating skeletal debris of fish in mudstones is thought to be minor, though this material is fairly common in tubular burrows.

The combined activities of predators and scavengers, and storm currents, adequately explain the thin concentrations of fish skeletal debris found throughout the Lower Colorado succession. However, this explanation fails to account for the spectacular abundance of laminar aggregates of fish debris in the Fish-Scale unit of the Big River Formation. These layers, up to 10 cm thick, and composed almost entirely of fragmented skeletal material of fish, suggest that mass mortality of fish was widespread in the Lower Colorado sea toward the close of Early Cretaceous time. Of the possible causes (Brongersma-Sanders, 1957), death caused by blooms of noxious dinoflagellates in coastal regions seems most plausible. These might have appeared seasonally or at irregular intervals. It is difficult to envisage alternative causes, such as basin-wide salinity or temperature changes. That algal blooms may be of importance on a basin-wide scale is demonstrated by the spread of coccoliths at the beginning of Turonian time.

Interfacial Assemblages of Microfossils

Interfacial assemblages of microfossils are for the most part restricted to type-II elements with green and subordinate, drab, very fine and fine-grained sandstones in the Joli Fou Formation. The sandstone layers are cross-laminated, occasionally ripple-drift, and have regular interfaces with shallow scour markings and numerous tool markings. Commonly foraminiferal tests are randomly distributed at a given interface, where they occur with abundant *Inoceramus* prisms and other fine pelecypod debris, ostracode carapaces, ophiuroid ossicles and fish remains. Elongate forms, such as *Ammobaculites*, frequently display orientation with long axes parallel to the lineation as defined by current markings, and tests of *Ammobaculites* and *Haplophragmoides* are occasionally found at the down-current ends of groove moulds. Interfacial assemblages consisting almost entirely of ostracode carapaces and fine pelecypod debris (Pl. XXI, Fig. 2) are fairly common.

The Joli Fou type-II layers are deduced to have been emplaced by storm-augmented tidal currents. Slow deposition of mud was interrupted by erosion to form a new depositional interface which was then quickly buried under sand. Where tests in an interfacial assemblage are also abundant in the subjacent mudstones, it is likely that lateral displacement is small. Such displacement is clearly minimal for preservation of entire ophiuroid arms at erosional interfaces. Foraminiferal tests, ostracode carapaces and pelecypod debris are frequently concentrated in interfacial scour markings (Pl. XXI, Fig. 2), as well as in scour-modified, exhumed trails and burrows. There are also instances in which microfossils and fine macro-invertebrate debris are concentrated at erosional interfaces in burrows clearly post-depositional to the sandstone layers.

Trace Fossils

The environment-controlled composition of trace-fossil assemblages to a large extent varies according to the association of elements within it. Type-I and muddy type-II elements tend to be characterized by diminutive, flattened tubular burrows, which may be straight or sinuous, simple or branched, occurring in the plane of the bedding. Complex, branched forms, usually with a mud infilling and variably oriented with respect to the bedding, are recognized in siltstone intercalations of these elements, as well as in the siltstones and fine-grained sandstones of sandy type-II elements and, more rarely, in type-III elements. Type-II elements display a fairly wide variety of mud and sand-filled, tubular forms of larger dimensions, preserved as both positive and negative epi- and hyporeliefs and as full reliefs in sandstones. They are especially well developed in the Joli Fou Formation. The trace fossils of type-III elements in the Viking Formation (Table 4) are typically larger and include abundant rhizocorallids and subordinate, though locally common, alectorurids, as well as sand-filled U-tubes and bundles of sub-horizontal tubes. However, type-III elements of other units do not exhibit such diversity. Type-IV elements of the regressive phase (Table 4) are characterized by low density of burrows and large trace fossils. They contain vertical sand-filled tubes, which may attain lengths of a metre or so and are usually connected to horizontal tube systems. Relatively scarce rhizocorallids and alectorurids also occur. Scarce vertical and horizontal sand-filled tubes are also recognized in the sandy type-V elements. Likewise, mud-filled rhizocorallid and alectorurid burrows and branching mud-filled tubes are frequently found in bentonite and bentonitic mudstone. Also, Joli Fou phosphate nodules are occasionally transected by vertical, phosphatized tubes. Rhizocorallids and

LOCATION IN MARINE BASIN TRACE FOSSILS	NEARSHORE DEPOSITS	PROXIMAL SHELF DEPOSITS	DISTAL SHELF DEPOSITS
Thalassinoides and related forms	common; wide, deep burrows	scarce; wide, shallow burrows	absent
Spirophyton	locally abundant	locally abundant	scarce
Rhizocorallium	occasionally recognized	occasionally recognized	absent
Teichichnus	scarce; wide, deep burrows	abundant; wide, deep burrows	scarce; narrow, shallow burrows
Phycodes	scarce	locally abundant	scarce
c.f. *Tisoa*	absent	abundant	occasionally found
Chondrites	scarce	abundant	abundant
c.f. *Daedalus*	absent	scarce	absent
frequency of occurrence and size	restricted range of ichnogenera - large forms sparsely distributed	wide diversity of ichnogenera - large and small forms often closely spaced	restricted range of ichnogenera - sparsely distributed diminutive forms
bioturbation	primary lamination destroyed only over minor thicknesses of sediment	primary lamination frequently destroyed but trace fossils in some units well preserved	primary lamination frequently destroyed

Table 4 — Trace fossil assemblages in deposits of the regressive phase of sedimentation, Colorado Group, west-central Saskatchewan.

branching systems of tubes in ferruginous silty mudstones occur below erosion surfaces (Pl. XXII, Fig. 1) within concretionary layers, rich in siderite and ankerite and incorporating siderite-filled and pyritized spherulites. It is evident that burrowing took place in conditions of slow deposition of fine sediment, which may have been arrested over long periods of time. That such concretionary layers may represent diastems provides support for the origin of siderite through marine cementation. Moreover, fairly abundant vertical pipes 10 cm long, as well as U-tubes, associated with flat upper surfaces of the concretionary layers are also present. These burrows, often filled with coarse sand also suggest low rates of deposition.

Trace-fossil assemblages are as follows:

(1) In the early Joli Fou, scarce, undetermined, vertical rhizocorallids and vertical, sand-filled tubes characterize type-IV elements of the nearshore region and are also found in these elements farther south. Branched systems of mud-filled tubes resembling *Chondrites* (Pl. XXII, Fig. 2) are also present in these elements and in type-II sandstones throughout the Joli Fou sequence. Sand-lined, mud-filled tubes, *Planolites* (Pl. XXII, Figs. 2 and 3) are common, as are sinuous, branched forms on sandstone soles, here termed *Sinusites*. There are scarce *Crossopodia* and a form resembling *Sagittichnus* (Pl. XXII, Fig. 4). Straight pre-depositional burrows, often filled with pelecypod debris and microfossils, are common. Vertical tubes filled with quartz grains and mud-filled tubes associated with them in type-II sandstones may represent escape traces of organisms buried by storm activities.

(2) The most abundant Viking assemblages occur in type-III elements of the proximal shelf deposits (Pl. XXIII) and include *Teichichnus*, *Rhizocorallium*, *Spirophyton*, *Chondrites*, *Phycodes* and paired vertical tubes similar to *Tisoa*. *Teichichnus* (Pl. XXIII, Figs. 1 and 2) is extremely abundant (compare with Jones, 1961a, b) giving rise to sets of inclined laminae similar to current-formed foresets (Pl. XV, Figs. 2 to 4) and often exhibiting mutually truncating relationships (Pl. XV, Fig. 5). The largest burrow forms of the type-III elements in the proximal shelf deposits are scarce, vertical, corkscrew-shaped forms over 30 cm long and wider than 8.75 cm core (Pl. XXIII, Fig. 4). These forms are tentatively assigned to the ichnogenus *Daedalus*. Scarce horizontal tubes of *Thalassinoides* also occur (Pl. XXIV, Fig. 1). The type-II elements of these deposits and type-III and II elements of the distal shelf deposits contain abundant *Chondrites* and relatively scarce *Teichichnus*. *Rhizocorallium*, *Teichichnus* and *Spirophyton* are fairly scarce in type-IV elements of the nearshore sediments, which are characterized by vertical (up to 1 m or so long) and horizontal, mud-lined, sand-filled tubes (Pl. XXIV, Figs. 2, 3 and 4) referable to *Thalassinoides*.

(3) The Big River features *Chondrites* and indeterminate, flattened sand-filled tubes in mudstones and siltstones. The latter burrows are occasionally pyritized and have the rounded cross-section preserved; fish and pelecypod debris and chert granules and small pebbles commonly fill the tubes in these cases. Flattened, straight or sinuous tubes in mudstone, each packed with ovoidal faecal pellets are fairly common. *Planolites*, occurring as pyrite-impregnated, sand-lined, mud-filled tubes, usually straight, flattened and sub-horizontal is abundant in type-III elements of the St. Walburg Sandstone.

(4) The sediments of both transgressive strata exhibit vertical passage upward and lateral change in N-S direction from near shore sandstones to distal-shelf mudstones. Some of the nearshore sandstones are strongly bioturbated, with subordinate mudstones, containing relatively simple, tube-like burrows of moderate size and accompanied by rhizocorallids in sediments of the early transgressive phase. The distal-shelf mudstones contain subordinate siltstones and fine-grained sandstones which are characterized by the general absence of churned lithologies and the predominance of complex diminutive mud-filled tubes (*Chondrites*). Because *Chondrites* is also widely distributed in the proximal shelf deposits of the Joli Fou, it seems likely that proximity of sand-depositing currents associated with the northern shoreline was more of a controlling factor than depth for the composition of trace-fossil assemblages. On the other hand, the pronounced northeasterly lateral passage from nearshore deposits with large, deep burrows including *Thalassinoides*, through proximal shelf sediments characterized by rhizocorallids, to distal shelf sediments containing scarce shallow rhizocorallid burrows and diminutive mud-filled tube systems, indicates bathymetric control of both trace-fossil assemblages (Seilacher, 1963, 1964, 1967) and depth of burrowing (Seilacher, 1964; Rhoads, 1966). This passage of trace-fossil assemblages is comparable to that in the Jurassic of England (Farrow, 1966). Comparison of the distribution of Joli Fou burrow morphologies with profiles through Recent nearshore bottoms, (Rhoads, 1966; Ohshima, 1968), suggests that the relatively well sorted sediments, here termed nearshore, include intertidal deposits.

Minute holes, up to a millimetre wide and several millimetres deep, in phosphate nodules of the Joli Fou and Viking Formations, are interpreted as borings. The borings are normal or slightly oblique to the surface and have smooth walls, lined with a layer of dark mineral (manganese?) up to 0.5 mm below the surface (Pl. XXV, Figs. 1 and 2). The holes may terminate downward in voids, which are probably moulds of the boring organism (Pl. XXV, Fig. 3) and also in sand-filled cavities (Pl. XXV, Fig. 4). Remanié borings filled with silica-cemented sand (Pl. XXV, Figs. 5 and 6) occur in the clasts of phosphatized wood found in conglomerates of the Viking Formation and probably preceded phosphatization.

The Depositional Environment

Life Conditions in the Lower Colorado Sea

Marine conditions marking the initial stages of the early transgressive phase were already established over much of the area at the onset of Lower Colorado deposition. Abundant, fragmentary skeletal remains of invertebrates are associated with interbedded sandstones and mudstones of the Spinney Hill built southward from a sandy marginal facies belt. The benthos was probably to a large extent made up of clams, oysters, brittle-stars, crustaceans, polychaete worms and agglutinating Foraminifera, occupying bottom muds in conditions of low rate of deposition. Skeletal material was concentrated in thin layers, together with exotic fragments, at times when tidal currents were augmented by storm waves. Locally there was intensive reworking of bottom sands and intercalated muds by burrowers. Parts of the Spinney Hill were probably deposited at depths ranging from 10 m to 100 m or more. Somewhat deeper marine conditions were attendant upon deposition of the upper Joli Fou muds.

The Viking regressive phase was characterized by the building northeastwards of beaches, barrier sand bodies and tidal sand ridges into the central facies belt from the inner sandy facies belt in the southwest. The nearshore Viking sequence appears to have been intertidal with a benthonic fauna of pelecypods and deeply burrowing crustaceans. The sandy shelf deposits show a pronounced proximal to distal decrease in size, depth and density of burrows and also in variation of burrow morphology. Thus the benthos, presumed from the nature of the burrows to be largely made up of crustaceans and polychaetes, probably displayed a corresponding northeasterly decrease in the number of groups involved, as well as some decrease in the size of individuals. The sand ridges of the North Sea occur at depths of 15 to 45 m (Haubolt, 1968) and this may have been the depth of similar features in shelf deposits during the Lower Colorado regressive phase. There was considerable biogenic reworking of muddy sands and silts during sedimentation and the increased plasticity of the sediment gave rise to load and injection phenomena. However, the stability of the reworked deposits was such that biogenic laminae of burrows are superbly preserved in retrusive sets. This latter mode of burrow construction reflects vertical movement close to the depositional interface, a response to rapid sedimentation in the general absence of any widespread erosion (see Seilacher, 1967).

Depths comparable to those of the Joli Fou transgressive phase were probably restored during the early part of the Big River transgressive phase, although supply of sand southward from the marginal zone was much reduced. The benthos appears to have consisted of agglutinating Foraminifera and clams, with some unknown contribution made by soft-bodied invertebrates. The burrowing activities of annelids are possibly reflected in the trace fossils and bioturbation of parts of the St. Walburg Sandstone. Dinoflagellate blooms are considered to have caused mass mortality of fish, prior to a general deepening of the basin, which latter still continued to support the same type of benthos up to the onset of Upper Colorado sedimentation. Late benthonic forms appear to have been largely restricted to clams; a flourishing plankton comprised coccolith-producing algae and pelagic Foraminifera, and ammonites and fish constituted the nekton.

Depositional Milieu

The mudstones of the Lower Colorado, by their very nature appear to reflect widespread, slow deposition of fine-grained terrigenous particles distributed by marine currents, fall-out of wind transported sediments and pelagic sedimentation of organogenic detritus (cf. Irwin, 1965). Joli Fou lithologies, especially the lowermost 7 to 10 m include calcareous orthoquartzites with phosphate bodies and fish remains, sideritic ooids and chert-rich conglomerates with reworked Mannville material. These are interpreted as palimpsest deposits (Swift *et al*, 1971), formed through reworking of relict sediments (Emery, 1968), which originated in depositional environments differing from that operative at the site of final burial. The numerous, thin intercalations of drab siltstones and fine-grained sandstones in the lower Big River mudstones, the Viking and the Joli Fou Formations, are considered to have been introduced from the shores by storm-driven currents. Upper Big River sedimentation of marine muds occurred by action of bottom currents and, by the onset of Upper Colorado sedimentation, pelagic rain of predominantly calcareous, organogenic debris took on great importance.

Glauconite is typically a product of the pre-burial stage of diagenesis (Dapples, 1962), arising mainly from diagenetic alteration of a variety of parent materials, especially those with a layered silicate lattice; this alteration frequently involves hydration and enrichment in iron, potassium and magnesium. Cloud (1955) provided a comprehensive account of factors limiting glauconite formation. The mineral originates in marine waters of normal salinity and is uncommon at depths less than 20 and more than 750 m. Glauconite forms in conditions of low sedimentation rate, especially on parts of the continental shelves distant from the mouths of major rivers. Optimum conditions of formation are slightly reducing and are thus found in the presence of decaying organic matter; possibly such conditions might also be obtained locally in a generally oxidizing environment (Burst, 1958). The most favourable parent materials appear to be micaceous minerals and bottom muds with a high iron content. The random microcrystalline internal structure (Triplehorn, 1966) most commonly found in Joli Fou glauconite grains offers little information on the process of formation. Thus it is not clear whether the glauconite resulted from alteration of clay-mineral aggregates, gel formation or recrystallization of a pre-existing internal structure of a different nature. An origin through alteration of biotite (Galliher, 1936) is a strong possibility, since that mineral was supplied through fall-out of volcanic ash and probably also by erosion of biotite-rich metamorphic rocks of the Precambrian Shield, especially those belonging to the Wollaston trend (Money *et al.*, 1970). Because the glauconite content of the Spinney Hill Sandstone increases northward and northeastwards and intercalated mudstones contain comparatively minor amounts of the mineral, it seems likely that the Spinney Hill glauconites were formed relatively close to the northern shoreline and were subsequently redistributed by marine currents.

The precipitation of sedimentary phosphate also takes place during the pre-burial stage of diagenesis and in conditions of slow sedimentation or non-deposition. The most favourable conditions appear to be in shallow, warm water, in the depth range 30 to 300 m (Bromley, 1967). Sedimentary phosphate deposits are known to be associated with areas of oceanic upwelling of phosphate-enriched water in a warm climate (Sheldon, 1964). Phosphate is then deposited on shelf areas by conversion to apatite of skeletal material resulting from the abundance of organisms promoted by the phosphate-rich water. Another alternative is direct precipitation of calcium phosphate by increase in pH of the upwelling water near the surface (Krauskopf, 1967). Considerations of phosphate deposits on the banks off southern California led Emery (1960) to suggest colloidal deposition of calcium phosphate from up-welling sea water. Bushinskiy (1963) claims that river-supplied phosphate is important in the formation of near-shore deposits, on the basis of Russian and Chinese occurrences in shallow-water sediments. Tranquil deposition and phosphatization of calcium carbonate alternate with winnowing and enrichment by increased current activity. Initial formation of phosphate deposits in estuaries, followed by reworking and redeposition in shallow marine sediments is envisaged by Pevear (1966) for Miocene phosphates of Maryland, Carolina and Florida.

Phosphate impregnation of Joli Fou intraformational sandstone clasts does not appear to have taken place *in situ*, since at most there is only minor replacement of calcite cement in associated sediments by phosphate. Thus transportation over short distances from shallow to slightly deeper water remains a possibility. The nodules occurring in the Joli Fou mudstones, however, are considered to have undergone little or no transportation, save for possible concentration through winnowing. On the other hand, some individual nodules appear to be made up of phosphate floccules ranging in size from clay to silt and even fine sand; these are evidence of current activity where they are organized into ripple cross-laminae. Both marine-organic and terrigenous-inorganic origins of phosphate may be invoked to give an immediate source for the Lower Colorado deposits; indeed, it is likely that both types of source were available. Granitic and pegmatitic rocks of the Shield with apatite as a common accessory mineral (Forsythe, 1968) provided a possible land source of phosphate, as did Paleozoic limestones, which during Cretaceous time probably covered at least part of the present Shield area and which may have contained phosphate as a minor constituent (compare with Krauskopf, 1967, p. 90). A biogenic origin of phosphate is provided by abundant skeletal remains of fish and shells of lingulid brachiopods.

The formation of siderite is favoured in conditions of negative Eh, low sulphide concentration, high ferrous ion mobilization and presence of carbon dioxide (Curtis and Spears, 1968). Iron may be introduced into marine basins as coatings of ferric oxide on the micelles of detrital clays (Carroll, 1958) and is converted to soluble, mobile, ferrous ions in reducing conditions. Such reducing conditions may be encountered between 20.5 and 40 cm below the depositional interface in outer-shelf muds, while nearer the surface, oxidizing conditions are found (Friedman *et al.*, 1968). Ferrous ions from the reducing zone migrate upwards during compaction to be oxidized near the surface and precipitated as the oxide and hydroxide. Continued burial would bring about a return to reducing conditions, in which the newly formed ferrous ions could react with carbon dioxide, produced through the decay of organic matter, to give siderite (Sellwood, 1971).

The above explanation, supported in part by body and trace-fossil evidence, was provided to account for the origin of siderite layers in the marine Pliensbachian of Yorkshire, and is also applicable to Lower Colorado concretionary siderite layers in west-central Saskatchewan. Likewise, erosional surfaces, marked by downward projecting burrow systems, indicate minor diastems. Furthermore, localized nodular and thin, intermittent, stratiform pyrite in the lower parts of siderite layers are consistent with the creation of the deduced reducing microenvironments.

Optimum conditions for the formation of sedimentary pyrite in marine deposits require organic matter and iron in, or adsorbed upon, detrital clays, as well as tranquil sedimentation of fine particles. According to Berner (1970), the principal stages of pyrite formation are:

(1) anaerobic bacterial reduction of sulphate ions from sea water, taking place within the sediments to give hydrogen sulphide;

(2) reaction of some of the hydrogen sulphide with the more reactive forms of iron to form iron monosulphides;

(3) reaction of iron monosulphides with elemental sulphur, formed through the oxidation of hydrogen sulphide, giving pyrite in the form of minute, framboidal spheres.

Such spherical bodies may be concentrated by winnowing of the bottom muds. Subsequent partial dissolution and replacement by pyrite of components of the silt and sand layers, gave rise to the stratiform pyrite concretions in the Lower Colorado.

Skeletal aragonite is extremely scarce in the Lower Colorado as a whole. This cannot be due to a general absence of source organisms since the most obvious faunal components are the prismatic layers of pelecypod valves, notably *Inoceramus*, occurring in absence of their aragonitic nacreous layer. The paucity of moulds or cement-filled casts of the pelecypodal nacreous layers suggests that aragonite removal was an early diagenetic phenomenon. Aragonite is soluble in natural waters and may undergo dissolution, to be either dispersed or redeposited as calcite (Chave, 1964). Bathymetric implications of carbonate dissolution have been studied by Hudson (1967), who concludes that selective dissolution of aragonite may proceed at less than the compensation depth at which supply of solid calcium carbonate is balanced by loss through dissolution. Thus preservation of Lower Colorado skeletal calcite implies depth of deposition not exceeding a few hundred metres, and a low rate of deposition in relation to the supply of shell material. Possibly the locally abundant calcareous cement of both drab and green sediments is the result of recrystallization of aragonite as calcite.

The Spinney Hill exhibits a generalized size fractionation of detrital grains, such that there is southerly increase in both the proportion of very fine and fine-grained sandstone and the overall intercalated mudstones. The interbedding relationships of the Spinney Hill Sandstone are similar to those of Recent deposits described by Straaten (1959) as fluviomarine. The latter are rhythmically stratified deposits laid down on the tidal upper reaches of deltas and in estuaries where there is interaction of fluvial, tidal and wave-generated currents. For the purposes of the present account, it is convenient to recognize two main types of deposit within the Spinney Hill Sandstone:

(1) *proximal fluviomarine deposits* of the marginal facies belt, characterized by fairly well sorted, fine to coarse-grained sandstones with subordinate mudstone intercalations;

(2) *distal fluviomarine deposits* of the central facies belt, featuring fine-grained sandstone and a southerly increasing mud content.

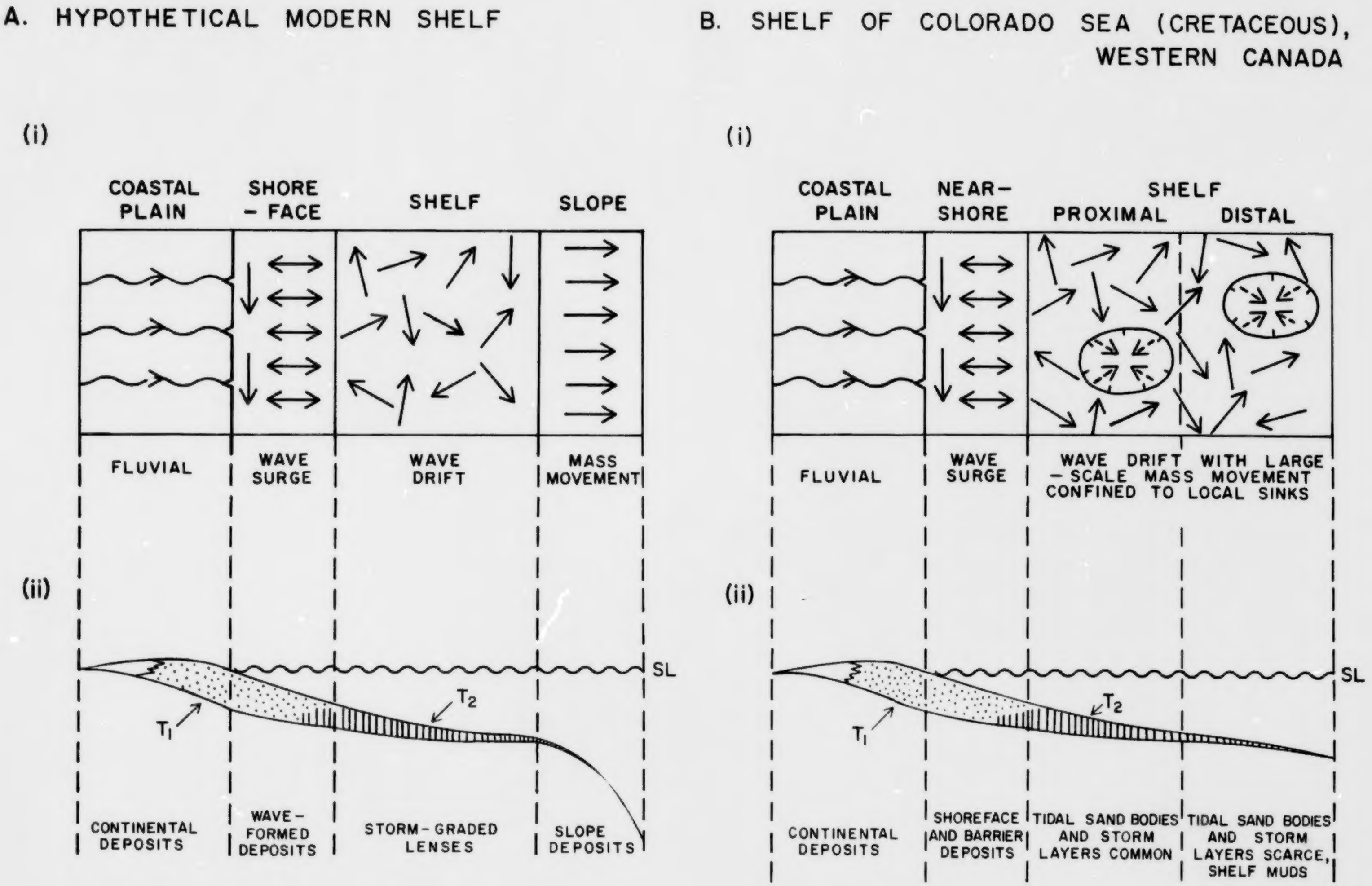
Textural differentiation in the Viking Formation is marked by passage from well-sorted sandstones to poorly-sorted and increasingly finer-grained lithologies before wedging out in a northeasterly direction. This broad pattern is best explained as resulting from sedimentation on a size-graded shelf (Shepard, 1932), the deposits of which became finer-grained with increasing distance from the shore. It is convenient to recognize three main Viking lithologic associations (cf. Swift *et al*, 1969), designated according to position relative to the postulated shoreline:

(1) *nearshore deposits*, characterized by thick well sorted sandstones in the south and southwest of the study area;

(2) *proximal shelf deposits*, largely made up of poorly sorted, often coarse-grained sediments, as well as alternations of fine-grained sandstone and mudstone, and occurring south of Township 33;

(3) *distal shelf deposits*, containing poorly sorted, fine-grained, muddy sandstones and siltstones, with scarce pebble layers.

Modern examples of graded shelves are not found (Shepard, 1932), because present-day shelves appear to reflect early stages of a return to the graded condition, following the disruptive effects of Pleistocene fluctuations in sea-level (Curray, 1964, 1965). However, theoretical considerations and observations of processes operative on modern shelves, together with a knowledge of the textural characteristics of ancient sediments (Fig. 34), provide a basis for determination of the feasibility of the graded-shelf response model as applied to ancient environments (Swift *et al*, 1969; Swift, 1970). Nearshore deposits are thought to have arisen through settling of particles of a given size at particular null lines, characterized by oscillating equilibrium of wave-surge and gravitational forces affecting the particles, to give a seaward-fining textural gradient on the shoreface (Miller and Zeigler, 1955; Johnson and Eagleson, 1966; Murray, 1967). On the other hand, the proximal and distal shelf deposits probably arose by random-walk dispersion with net seaward transport of particles, brought about by currents both storm-generated (Swift, 1970; Swift *et al*, 1971), and tidal. Although observations of relatively short-term effects suggest that movement of sand seaward from the shoreface is not extensive (for example, Dietz, 1963; King, 1963), the significance of "rare events", such as wave drift currents generated by storms, is likely to have been great in long-term processes of sand dispersal (Curray, 1960; Zenkovich, 1962; Moore and Curray, 1964; Draper, 1967) and particularly over long periods



A. HYPOTHETICAL MODERN SHELF

B. SHELF OF COLORADO SEA (CRETACEOUS), WESTERN CANADA

(i)
COASTAL PLAIN
SHORE - FACE
SHELF
SLOPE
FLUVIAL
WAVE SURGE
WAVE DRIFT
MASS MOVEMENT
(ii)
SL
T1
T2
CONTINENTAL DEPOSITS
WAVE-FORMED DEPOSITS
STORM-GRADED LENSES
SLOPE DEPOSITS
(i)
COASTAL PLAIN
NEAR-SHORE
SHELF
PROXIMAL
DISTAL
FLUVIAL
WAVE SURGE
WAVE DRIFT WITH LARGE-SCALE MASS MOVEMENT CONFINED TO LOCAL SINKS
(ii)
SL
T1
T2
CONTINENTAL DEPOSITS
SHOREFACE AND BARRIER DEPOSITS
TIDAL SAND BODIES AND STORM LAYERS COMMON
TIDAL SAND BODIES AND STORM LAYERS SCARCE, SHELF MUDS

Figure 34 — Comparison of sediment-dispersal patterns and shelf morphology on a modern, marine shelf and the shelf of an epeiric sea (based on Swift, 1969).

A — hypothetical modern shelf; B — shelf of Colorado sea (Cretaceous), western Canada; T_1 *and* T_2 *are successive time lines.*

characterized by slow deposition of muds. However, the importance of storm layering decreases in the direction of attenuation of the Viking Formation. Lithologic characteristics suggest that tidal currents were important throughout the Viking shelf area, giving rise to large-scale sand bodies in the proximal part and locally thickened sand developments in the distal part. Similar depositional processes were probably operative during sedimentation of the St. Walburg and Flotten Lake Sands of the marginal facies belt. Thus, within the study area, sediment size-fractionation took place both from the inner facies belt (regressive phase) northeastward and from the marginal facies belt southwestward to the extent that the intervening central facies belt is dominated by mudstone. Furthermore, this lateral fractionation in two principal, opposing directions takes place in a sequence which thins markedly in a northerly direction. Even if effects of compaction are taken into account, Lower Colorado patterns of deposition appear to have little in common with those of the shelf-slope environments adjacent to modern continents. However, as noted by Curray (1969), it is unlikely that ancient shelves exhibited the abrupt increase in slope at the shelf break, which reflects erosion attendant upon lowered sea-level on some modern shelves. Furthermore, the morphology of pre-Quaternary continental shelves was controlled to a large extent by the balance between rate of deposition and rate of subsidence (Curray, 1964, 1969). Concepts of shelf sedimentation based on studies of modern conditions can be applied to stratrigraphic successions deposited in epeiric seas, when the width assigned to the inner shelf is greatly increased as part of a broad definition of the term "shelf" (Swift, 1969). This accounts for the gentle slopes, vast dimensions and shoal character deduced for ancient epeiric seas.

Mode of Deposition

Most workers have favoured a shallow-water, marine origin for the Lower Colorado of western Canada, such that sands reflect a variety of nearshore environments, postulated mostly on the basis of gross geometry of units. The objections of DeWiel (1956) and Jones (1961a, b) to a turbidity-current origin for the Viking Formation (Beach, 1955), are adequate for purposes of the present account. Furthermore, it is most unlikely that conglomerates of the Viking Formation were emplaced as a result of single, "catastrophic" events, such as violent storms or, as proposed by Beach (1956), tsunamis. Certainly the nearshore, sedimentary record of the hurricanes Donna and Betsy, both of which passed over the Florida Keys and Florida Bay (Perkins and Enos, 1968), includes only minor thicknesses of sand and mud and coarser material supplied from eroded beaches by the ebbing storm tide. However, storm action is the only feasible mechanism, which might be effective in transporting pebbles and cobbles past the surf break (Swift, 1970). Once on the shelf, coarse clasts can be transported by currents and concentrated through selective removal of fines. Sand and gravel fractions may be segregated to a large extent in discrete patches on the bottom, and gravel layers may be preserved through growth of sand patches upon them (Belderson and Stride, 1966). Moreover, sands can be moved by tidal currents, while adjacent gravel patches might only be moved by storm waves, as described by Flemming and Stride (1967) for the English Channel. That segregation of size grades is not always obtained on tide-swept sea floors, subjected occasionally to storm activity, is evidenced by the dunes of sandy gravel in the Celtic Sea (Kenyon, 1970). Thus tidal currents, augmented from time to time by storm waves, could have created all bedding features observed in the coarse-grained sediments of the Viking Formation.

The regular alternations of Lower Colorado coarse siltstone or fine sandstone and mudstone layers of type-I and type-II elements, locally graded from sandstone to mudstone, most closely resemble turbidite sequences. Indeed, Hayes (1967) reports the occurrence of similar layers in the Gulf of Mexico and suggests that they resulted from turbidity currents generated by hurricanes. The type-I and type-II predominantly very fine and fine-grained sandstones of the Joli Fou and lowermost Big River Formations, in many cases originated in muddy shelf conditions as "storm layers" (Reineck *et al*, 1968), comprising sands transported from coastal areas by storm waves. Support for this mode of origin comes from accumulations of shell debris, ranging from whole valves to single calcite prisms, near the base of the Joli Fou sandstones (cf. Reineck *et al*, 1968, Fig. 6, p. 271).

It follows that at least the lowermost part of each mudstone layer separating successive sandstones may reflect deposition from suspension as storm waves gradually die out. Another characteristic feature of the type-II sandstone layers is the presence of horizontal or very gently inclined laminae. Horizontal laminae may form when a gradually decelerating suspension current flows over a flat bottom and sedimentation is gradual (Kuenen, 1966). There is then a tendency for particles of equal weight, density and shape to settle out of suspension together to form first isolated patches and later continuous laminae. Reineck and Singh (1972) attribute storm layers in shelf muds to the settling of sand and silt from storm-generated suspension clouds with decrease in wave energy. Ripple laminae may occur in the upper parts of the sand layers (Reineck *et al*, 1968). Mass movement of sediment downslope under the influence of gravity is thought to be confined largely to avalanching of grains from low shoals into adjacent shallow troughs thereby producing the coarse-grained intercalations in type-II elements, possibly after reworking by bottom currents. Such a mechanism would provide an explanation for occurrences of some thin, cross-laminated glauconitic sandstone in mudstones of the Joli Fou Formation. Likewise, phosphate nodules formed in conditions of non-deposition or low rate of sedimentation on shoals might have been redeposited with glauconitic sands in adjacent troughs.

There is ample evidence of current activity during phases of dominant mud deposition producing type-I and type-II elements. Ferruginous concretions and phosphate nodules in the Joli Fou and the widespread ferruginous concretions in the Viking and lowermost Big River Formations are taken to indicate low rates of sedimentation, though current activity is reflected in erosion surfaces and cross-lamination preserved within the concretions, as well as in the cross-laminae of bentonites and bentonitic mudstone. Recent work on sediments of the Southern Bight of the North Sea suggests that suspended sediment concentration of waters, near-bottom current velocity and magnitude and frequency of wave activity, control the mud content of bottom deposits (McCave, 1970). Along the Dutch coast, high concentrations of suspended sediment are encountered in the nearshore zone (Terwindt, 1967) and in spite of the high wave activity, mud comprises up to 20 per cent of the bottom sediment (Straaten, 1965; Eisma, 1968; Houbolt, 1968). Farther offshore, concentrations of suspended material are low and the mud content of the bottom sediment is much reduced (Eisma, 1968), so that slow deposition of mud appears to be offset by wave and current action. As noted by Postma (1967), settling and scour lag effects in conjunction with tidal movements can give rise to landward transport of mud in nearshore, tidal-flat and estuarine areas and flocculation may be important in promoting deposition. Analogous shoreward concentration of mud appears to be reflected in parts of the Bow Island sequence of southern Alberta, where lenses of sandstones and conglomerates are separated vertically and laterally by mudstones. Furthermore, although type-II sandstone-mudstone alternations may represent sand deposition during phases of strong tidal currents with mud laid down during times of slack water (see Straaten, 1965), mudstone intercalations in type-III, IV and V elements may reflect no more than localized and short-lived increases in suspended sediment without fluctuation in either current velocity or wave activity.

The fairly common groove markings and comparatively scarce scour markings, of the type-I, II and IV elements, provide little additional information as to the mode of deposition of the superjacent sands. Such structures are not restricted to turbidite sequences and relatively deep-water environments (Dzulynski and Simpson, 1966) or shallow-water occurrences as recorded by Panin (1965). In the absence of oriented cores of the Lower Colorado sequence, little may be determined about directions of sand transport. The dip direction of cross-laminae resting on a given erosional interface is usually parallel to the dominant trend of interfacial structures. However, succeeding sets of cross-laminae, where they occur, may diverge greatly. Similar assemblages of interfacial structures have been observed by the author in the Blackleaf Formation of north-central Montana and in the Mowry Shale of the Morrison Dome in the Little Rocky Mountains, Montana.

Intensive bioturbation of sediment as recorded in the extensive Viking type-III elements, is known from shallow-water and marginal marine environments and reflects organic activity at or immediately below the depositional surface, penecontemporaneous with sedimentation (Moore and Scruton, 1957). The extent of bioturbation is essentially determined by the capacity of burrowers to occupy a given substrate and keep pace in their sediment-reworking activities with deposition. The coarsening-upward nature of many Viking type-III elements, appears to reflect increase in current activity and possible deterioration of life conditions. Varying substrate mobility, in response to fluctuation in sand supply and possible changes in current strength, is evidenced by thin intercalations of well sorted ripple-laminated sandstone within type-III elements. Extensive bioturbation of the type described above is also recorded, for example, from large-scale sand ridges in the Southern Bight of the North Sea (Houbolt, 1968), from the open shelf of the Rhone delta (Straaten, 1959) and from the shoreface of Galveston Island (Bernard *et al*, 1962). These examples represent pronounced differences in physiographic and hydrologic settings. Ancient analogues are provided by the sandstones of the Cretaceous Blackleaf Formation of northern Montana, which probably originated as marine offshore bars, barrier islands or shoreline sands (Cannon, 1966), and the lowermost sandstone unit of the Upper Cretaceous Eagle Sandstone, interpreted as a barrier-island deposit (Shelton, 1965).

The loading and injection phenomena reported from Viking type-II and III elements indicate, in most instances, the response by spontaneous liquifaction of soft, unconsolidated sands to a relatively abrupt increase in super-incumbent load, especially by deposition of coarse-grained type-V elements. A similar origin is readily acceptable for complex lateral-displacement structures of some Viking type-II elements, constituted of recumbent folds and piled lumps of contorted sediment, especially where these are overlain by type-V elements. Shear failure may also be induced in such sediments by movement of a dense sediment in traction over the depositional interface. In the Joli Fou sequence, where sandstones are thin and coarse clastic material scarce, the common vertical and lateral-displacement structures may have originated as shear caused by pressure changes associated with the movement of waves. Evidence for this latter mechanism comes from the landslide area of the Birdfoot Delta of the Mississippi River, (Fisk and McClelland, 1959) and Henkel (1970), where the depositional surface has an average slope of ½ degree. Wave-induced failure of soft sediment may take place down to depths of 120 m and arises through net downslope movement resulting from wave-imposed oscillatory motion of the sediment, as well as reduction in shear strength by repeated reversal of stress in the sediment (Henkel, 1970). Net unidirectional trends of movement transferred from bottom currents will presumably give rise to failure of bottom sediment on slopes of less than ½ degree. Extensive clastic intrusions in the Skull Creek Shale (Russell, 1927; Wulf, 1962) were traced for over 30 m laterally and up to 7.5 m vertically.

The generalized regime classification of flow in alluvial channels (Simons and Richardson, 1961; Simons *et al*, 1965) is based on bottom configuration, mode of particle transport, process of energy dissipation and phase relations between bottom and water surfaces:

(1) The *lower flow regime* is characterized by high resistance to flow, small sediment transport, out-of-phase relations between water and bottom surfaces and prevalence of form roughness, with ripples and dunes produced through movement of particles in discrete steps up stoss slopes to be avalanched down lee faces.

(2) The *upper flow regime* has low resistance to flow, large sediment transport, in-phase relations between water and bottom or antidunes produced by continuous sediment transport.

(3) There is also a *transitional flow regime* of variable resistance to flow and sediment transport, with bottom configurations typical for either upper or lower flow regimes developed, according to antecedent conditions.

Although wave-formed cross-lamination has been noted in the Lower Colorado succession, net unidirectional flow, comparable to that obtained in the lower flow regime, is reflected in ripple-formed cross-lamination, frequently including ripple-drift and trough types in all sequence elements. Well-sorted, fine-grained sandstones of type-IV elements frequently exhibit relatively large-scale sets of bipartite cross-laminae, often with horizontal laminae and laminar aggregates of pebbles. Dunes are a stable bed form in fine sand only over a narrow range of flow conditions (Guy, *et al*, 1966) and therefore it seems likely that the structures resulted from wave-produced, oscillatory currents (cf. Campbell, 1966, Fig. 1, p. 826). The horizontal and gently inclined laminae of type-II coarse siltstone and fine sandstone layers of the Pense and Viking Formations, probably also reflect oscillatory bottom currents. Evidence of upper flow regime appears to be largely confined to sets of horizontal pebbly laminae and structureless type-V conglomerates and diamictites in the Viking Formation. Fahnestock and Haushild (1962) and Gwinn (1964) describe movement of pebbles and cobbles on a sandy bottom in the upper flow regime. Harms and Fahnestock (1965) state that movement of particles in this size may be either intermittent or continuous in the transitional flow regime.

The influence of oscillatory particle motion upon the formation of cross-lamination in the Lower Colorado may not be adequately assessed from cores and the primary record is much obscured by bioturbation. However, in general terms the coarsening-upward associations of sequence elements in the Viking Formation represent conditions comparable to passage from lower to upper flow regime, whereas the fining-upward associations in the Spinney Hill Sandstone appear to indicate a change in the flow regime from upper to lower in many cases. Sedimentary structures, such as those described from Viking type-IV and laminated type-V elements in the south of the study area, are thought to be characteristic for shore, barrier-island and offshore bars in that coastal deposits represent considerable diversity in physiographic and hydrologic settings (e.g. Straaten, 1965; Milling and Behrens, 1966; Andrews and Lingen, 1969). The large-scale, composite, inclined stratification of the Dodsland-Hoosier trend suggests sand ridges similar to those in the North Sea (Houbolt, 1968), and subordinate occurrences of type-IV elements may reflect megaripples on the crests of such ridges (cf. Jordan, 1962; Off, 1963). On the other hand, the southward passage of type-IV elements into type-II in the Spinney Hill Sandstone seems to indicate tidal sand bodies associated with an estuarine sequence passing into delta, i.e. proximal deposits passing southward into distal. The study of sedimentary structures permits more detailed characterization of the environments postulated:

(1) Lower Colorado mudstones (Joli Fou, Big River, uppermost Viking) represent relatively low rates of deposition under conditions of bottom-current activity, probably tidal in origin. Evidence includes erosion surfaces and cross-lamination preserved in sideritic and phosphatic concretionary layers, which were formed through submarine cementation. Horizontal and gently inclined laminae, lenticular and wavy layering, as well as normal grading, in type-I and II coarse siltstones and fine sandstones, particularly numerous in the lowermost and uppermost parts of the Joli Fou, uppermost Viking and lowermost Big River Formations, reflect deposition from suspension under the influence of storm waves.

(2) The Viking Formation, except for the fine-grained uppermost part, appears to indicate regression on a graded shelf, in that increase in the admixed mud northeastward is accompanied by progressive change in assemblages of sedimentary structures

(Fig. 35). This latter is seen as a passage from a thick, nearshore sequence, in which type-IV elements of high porosity and permeability predominate, through a proximal shelf sequence of sediments with a wide range of porosity and permeability values and characterized by predominance of sandy type-III and type-II elements and sporadic occurrence of type-IV and V elements, to a distal shelf sequence, largely made up of muddy type-III elements of low porosity and permeability. This lateral succession suggests northeastward replacement of northwest trending shoreline or barrier sand bodies (nearshore region) by tidal sand ridges of northwesterly to westerly orientation with coarsening-upward associations of elements in large-scale, composite, inclined

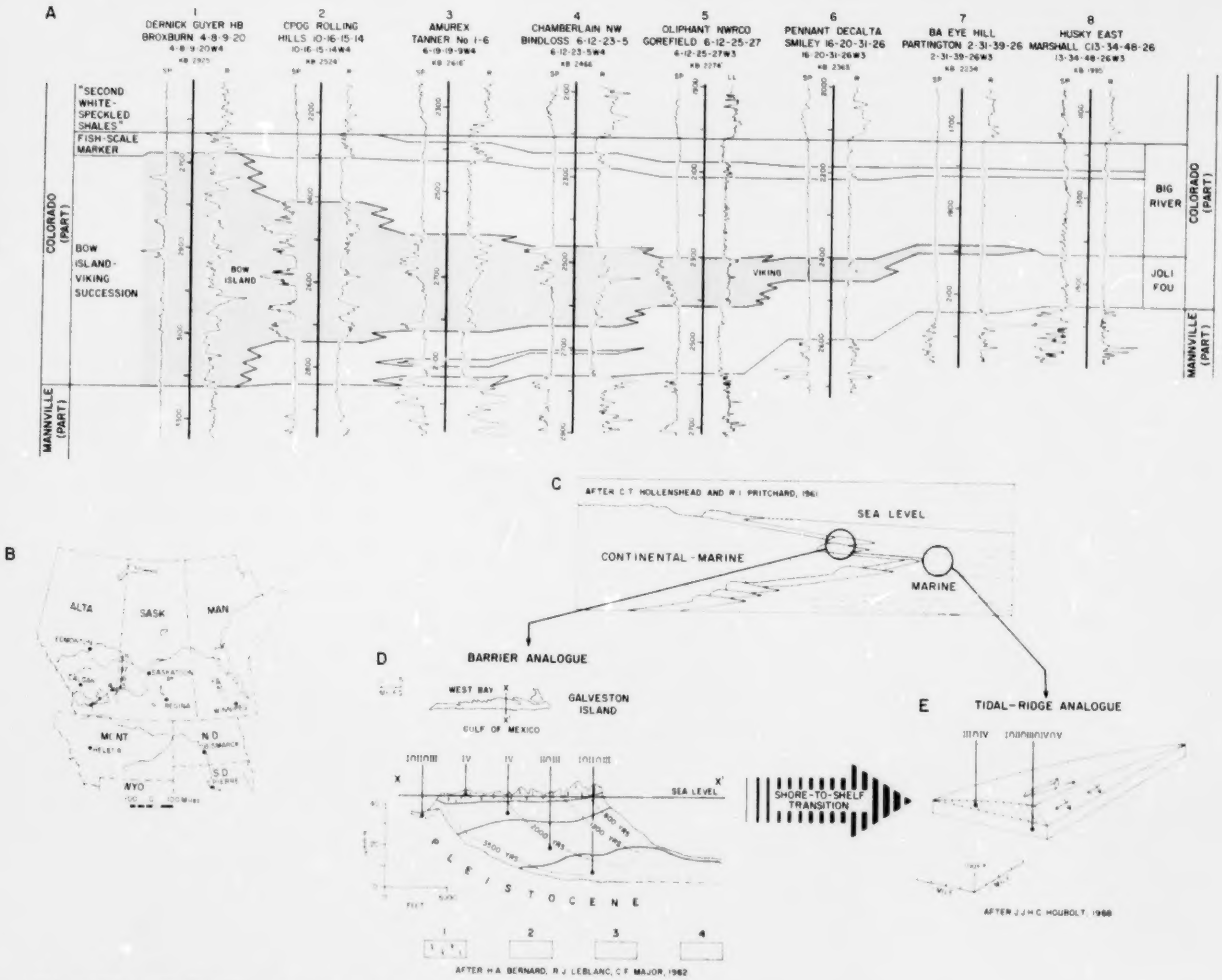

A
1
DERNICK GUYER HB
BROXBURN 4-8-9-20
4-8-9-20W4
KB 2925
2
CPOG ROLLING
HILLS 10-16-15-14
10-16-15-14W4
KB 2524
3
AMUREX
TANNER No 1-6
6-19-19-9W4
KB 2616
4
CHAMBERLAIN NW
BINDLOSS 6-12-23-5
6-12-23-5W4
KB 2466
5
OLIPHANT NWRCO
GOREFIELD 6-12-25-27
6-12-25-27W3
KB 2274
6
PENNANT DECALTA
SMILEY 16-20-31-26
16-20-31-26W3
KB 2365
7
BA EYE HILL
PARTINGTON 2-31-39-26
2-31-39-26W3
KB 2234
8
HUSKY EAST
MARSHALL C13-34-48-26
13-34-48-26W3
KB 1995
SP
R
LL
"SECOND WHITE-SPECKLED SHALES"
FISH-SCALE MARKER
COLORADO (PART)
BOW ISLAND-VIKING SUCCESSION
BOW ISLAND
VIKING
BIG RIVER
JOLI FOU
MANNVILLE (PART)
B
ALTA
SASK
MAN
MONT
N D
S D
WYO
C
AFTER C T HOLLENSHEAD AND R I PRITCHARD, 1961
SEA LEVEL
CONTINENTAL-MARINE
MARINE
D
BARRIER ANALOGUE
WEST BAY
X
X'
GALVESTON ISLAND
GULF OF MEXICO
SEA LEVEL
800 YRS
1800 YRS
2000 YRS
3500 YRS
PLEISTOCENE
FEET
1
2
3
4
AFTER H A BERNARD, R J LEBLANC, C F MAJOR, 1962
SHORE-TO-SHELF TRANSITION
E
TIDAL-RIDGE ANALOGUE
AFTER J J H C HOUBOLT, 1968

Figure 35 — The Bow Island-Viking succession and its modern analogues.

A — Stratigraphic cross-section of the Bow Island-Viking succession, southeastern Alberta and western Saskatchewan.

B — Location map showing line of section.

C — Schematic diagram to show development of a continental-marine, regressive-transgressive, clastic wedge.

D — Internal structure of modern barrier sand body. 1 — aeolian sands, 2 — beach and upper shoreface zone, 3 — middle shoreface zone, 4 — lower shoreface zone.

E — Internal structure of modern tidal sand ridge.

I to IV — sequence elements; in D and E symbol ∩ denotes association of sequence elements.

stratification incorporating storm layers (proximal shelf), passing into variably oriented, muddy sand bodies, in which storm layers are scarce (distal shelf).

(3) The fluviomarine Spinney Hill sediments in a north-south direction are marked by passage from a thick proximal sandy sequence, comprising type-IV elements with subordinate mudstone intercalations, to a thinner distal sandy sequence with important type-I and muddy type-II elements. Distribution of sands is thought to have been for the most part through lateral migration of tidal channels. The Flotten Lake Sand and St. Walburg Sandstone likewise display southerly thinning and decrease in grain size and are probably also largely of tidal origin.

Structure

Main Features

The dominant structural feature in the area (Fig. 36) is a homocline, which is part of a broad shelf extending from central Alberta across Saskatchewan into southern Manitoba. The strike is for the most part northwesterly or west-northwesterly and the dip is generally southerly, increasing southward from the order of 2 m per km to 5 m per km or more. In the southeastern part of the study area, the dip steepens to 9.5 m per km and turns southeast where the structural influence of the buried Watrous basin becomes significant. The homocline is modified to varying degrees, as a result of numerous, smaller-scale features, (Fig. 37), attributed to:

(1) irregularities of the Precambrian surface, some possibly arising through reactivation of stocks;

(2) differences of elevation caused by collapse of strata into solution channels, formed as a consequence of localized, partial or complete removal of salt in the Prairie Evaporite (Middle Devonian) by circulating water;

(3) the palaeotopography of the pre-Cretaceous surface.

In some cases, condition (2) may have resulted from the existence of condition (1), where Precambrian monadnocks diverted circulating formation waters upward into the salt deposits of the Prairie Evaporite. Thus conditions (1) and (2) may have exerted a control upon the texture of the eroded pre-Cretaceous surface.

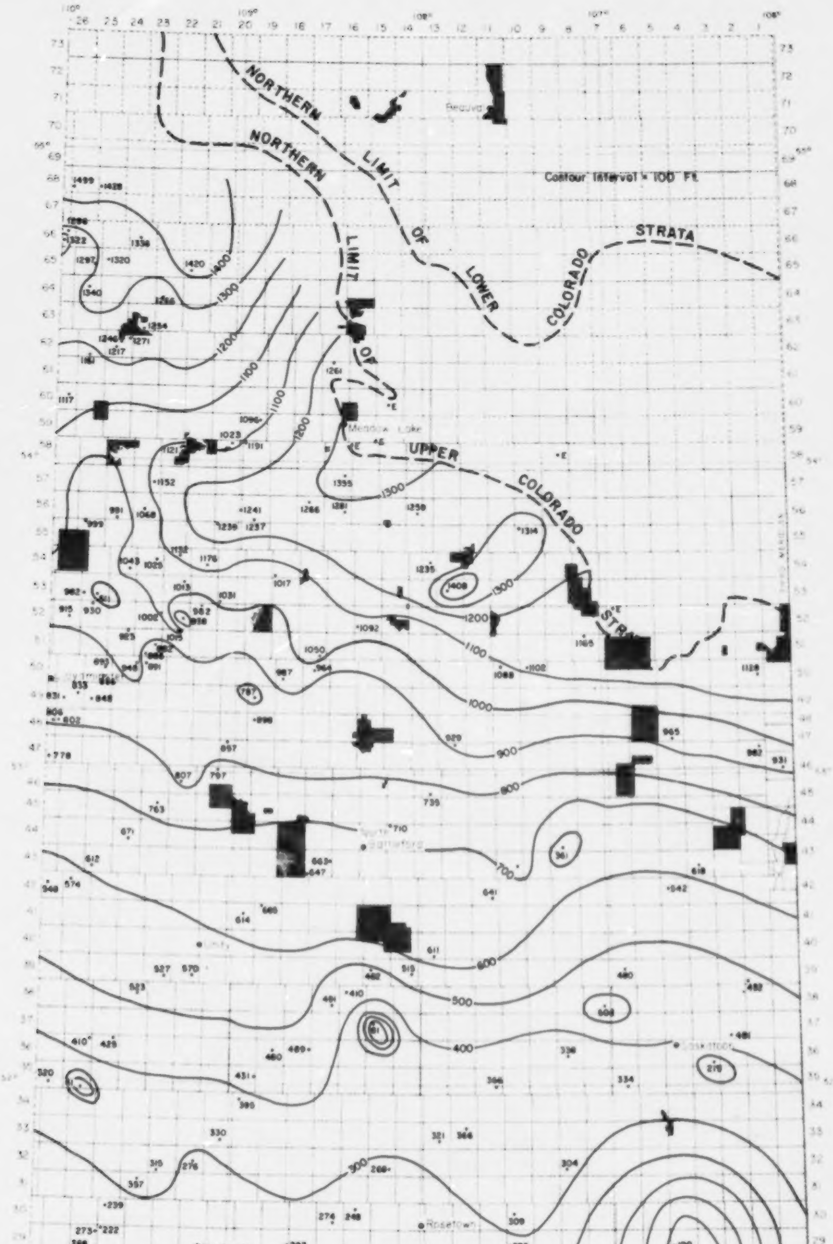
Western Shore-to-Basin Transition

Structures of deep-seated, epeirogenic origin are for the most part those located above positive irregularities of the eroded Precambrian surface. These include strong lineaments, as well as a number of pronounced domes and anticlines, such as the Sweetgrass-North Battleford arch, the axial trace of which enters Saskatchewan at the Fourth Meridian in the vicinity of the Dodsland-Hoosier production trend and extends through Unity to North Battleford.

That the Sweetgrass arch was elevated during Colorado time is suggested by the limited sedimentary record of the Lower Colorado regressive-transgressive sequence (upper Viking-basal Big River): The Viking is represented by a relatively thin, coarsening-upward sequence, for the most part less than 10 m thick, whereas the fining-upward record of transgression is only a metre thick. The abundance of thin siderite layers in the transgressive sequence at the top of the Viking Formation and near the base of the Big River Formation is indicative of chemical deposition of carbonates on the western shelf, at times when the supply of siliciclastic debris was arrested as a consequence of entrapment in shoreline settings. The limited eastward spread of regressive-transgressive deposits beyond the Sweetgrass arch suggests that the arch itself was of sufficient elevation to restrict the supply of Cordilleran debris. It should also be noted that the Viking sandstones located nearest the crest of the arch are well washed deposits and possibly reflect winnowing by currents at locations determined by arch geometry.

Deep seated structures of more localized occurrence include the Spinney Hill anticline (Fyson, 1961; Kent, 1968) and the Thickwood Hills anticline (Kupsch, 1956; Sawatzky *et al*, 1960) as well as the Birsay anticline and the Elbow and Lawson domes (Sawatzky *et al*, *loc. cit.*). The presence of Precambrian structural highs beneath these features was either proven by drilling or was deduced on the basis of geophysical data. A crypto-volcanic origin has been proposed for the Elbow structure (deMille, 1960), but it should be noted that Kent (1968) produced evidence suggesting several different episodes of solution of salt belonging to the Prairie Evaporite in the Elbow district, which no doubt were of importance in the development of the structure. Both the Elbow dome and the Thickwood Hills anticline have surface expression as positive topographic features (see Kupsch, 1956).

Major negative structural features on the surface of the Mannville Group (Fig. 38) are the Rosetown, Bladworth and Saskatoon troughs. The northwesterly trending Rosetown and Bladworth troughs coincide with areas from which the Prairie Evaporite is missing, (Kent, 1968; Holter, 1969). In addition, Kent (*loc. cit.*, Fig. 27) depicts the Saskatoon trough on the Devonian as overlying a northeast-trending salt-free area, more extensive than a similarly located, tentative area included on Holter's maps. Smaller-scale troughs of similar origin are the Duperow structure and numerous salt sinks scattered throughout the area. Salt removal appears to have taken place at varying rates over different intervals of geological time. The conclusions reached by previous workers regarding the dating of salt removal are summarized by Kent (*loc. cit.*, p. 88-90), whose own view is that late Middle Devonian salt removal, was restricted to narrow, local channels (Elbow sub-basin, Rosetown embayment), and was followed by more extensive solution and collapse in Late Devonian time (Elbow sub-basin, Bladworth and Saskatoon embayments). Further restricted solution took place in latest Devonian to Early Mississippian (Elbow sub-basin and associated embayments) with perhaps some removal during Mississippian to Early Jurassic times. A final stage of salt solution (Bladworth and Saskatoon embayments, Elbow sub-basin) occurred after the close of Cretaceous time.


Contour Interval = 100 Ft
NORTHERN LIMIT OF LOWER COLORADO STRATA
NORTHERN LIMIT OF UPPER COLORADO STRATA
Beauval
Meadow Lake
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Rosetown
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1400
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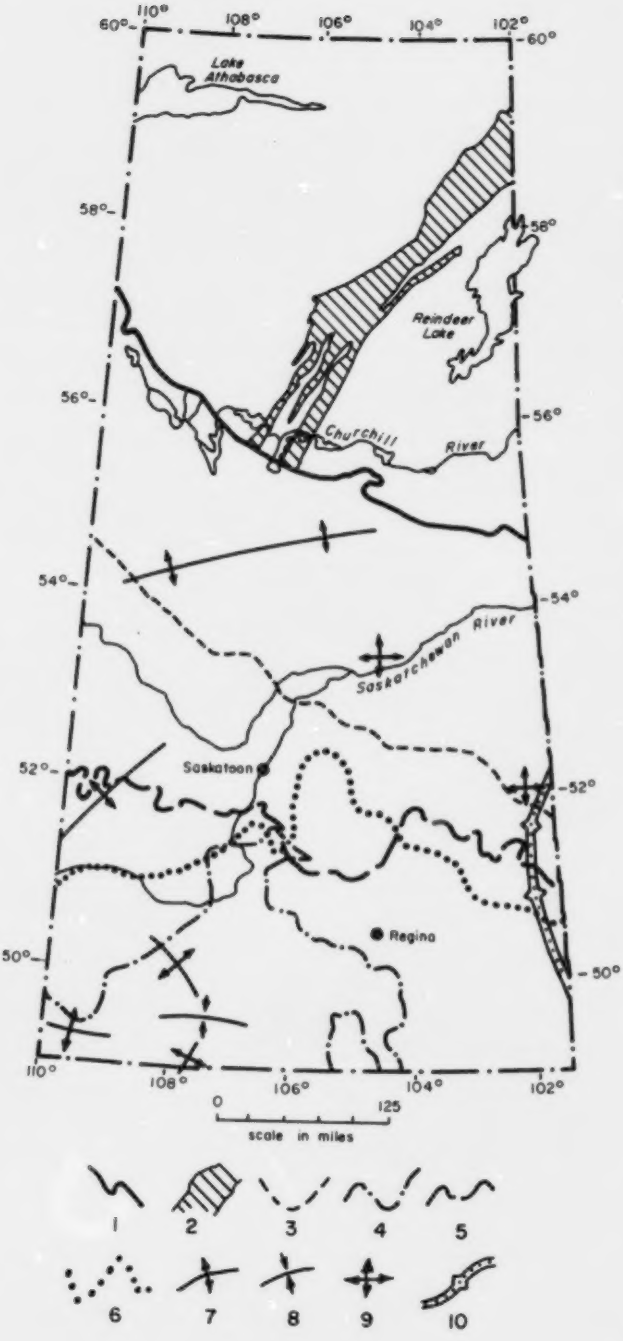
Figure 36 — General structure on the top of the Big River Formation in west-central Saskatchewan.


110°
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Lake Athabasca
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Reindeer Lake
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Churchill
River
54°
Saskatchewan River
52°
Saskatoon
Regina
50°
0
125
scale in miles
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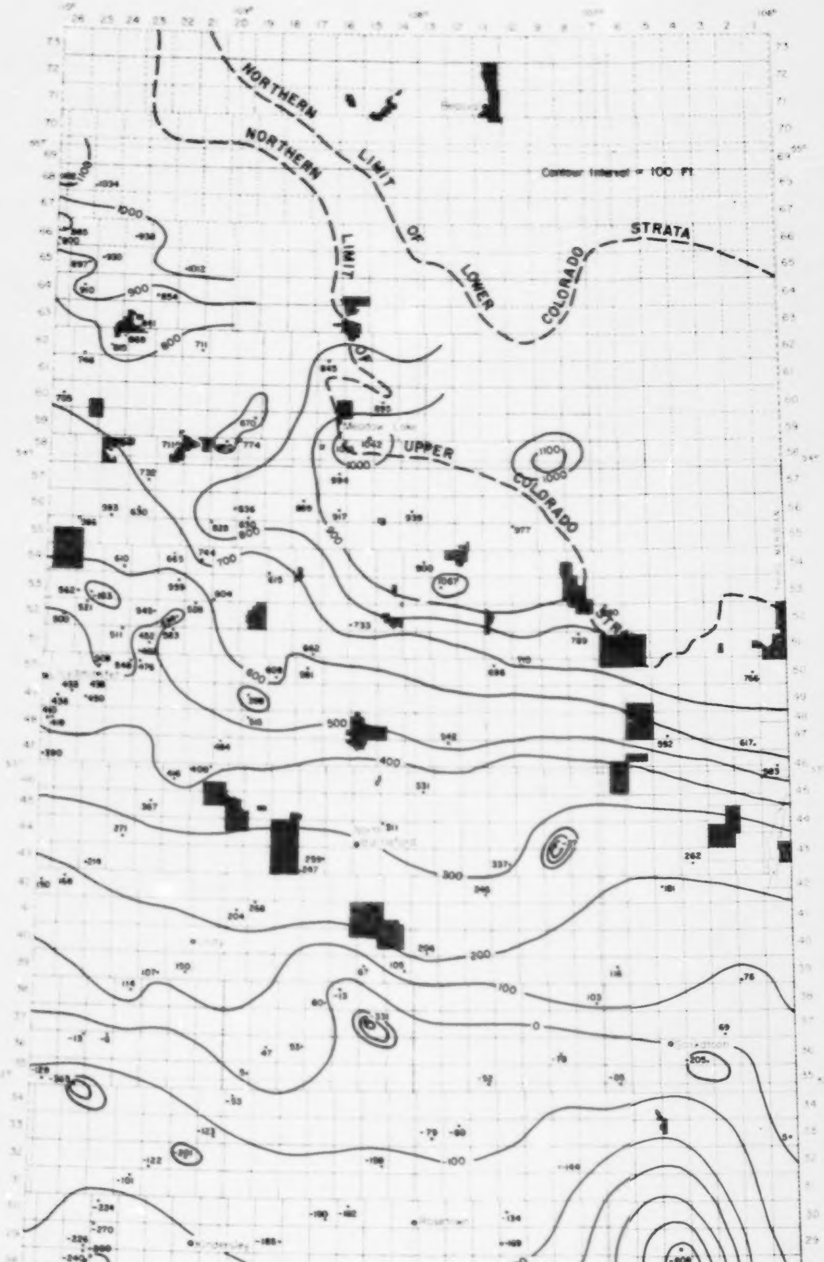
3
4
5
6
7
8
9
10

Figure 37 — Sketch map of main features controlling structure in the Colorado Group of Saskatchewan. 1 — southern perimeter of Precambrian Shield, 2 — Wollaston fold belt, 3 — northern limit of Prairie Evaporite salt, 4 — southern limit of Prairie Evaporite strata, 5 — limit of Mississippian strata, 6 — limit of Jurassic strata, 7 — positive basement linear, 8 — negative basement linear, 9 — domal feature, 10 — aeromagnetic/gravity anomaly.


NORTHERN LIMIT OF LOWER COLORADO STRATA
NORTHERN LIMIT OF UPPER COLORADO STRATA
Contour Interval = 100 Ft
Meadow Lake
North Battleford
Saskatoon
Kindersley
Rosetown
Elbow
1100
1000
900
800
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200
100
0
-100
-200
-300
-400
-500
-600
-700
-800

Figure 38 — General structure on the top of the Mannville Group in west-central Saskatchewan.

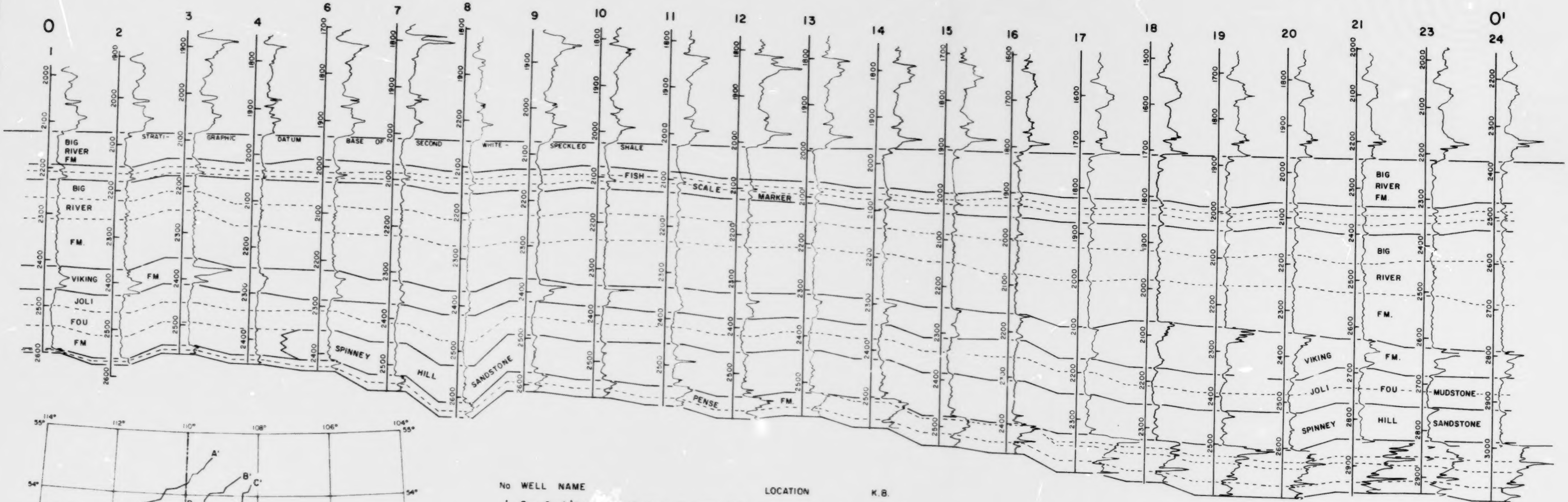
The pre-Cretaceous unconformity has exerted considerable influence upon structure within the Lower Colorado succession, in spite of the damping effect exerted upon drape-fold amplitude by the variable thickness of the Mannville sediments underlying the Colorado Group. This surface exhibits all structural features described above from the top of the Mannville Group and in addition displays large-scale relief features, predominantly of erosional origin, which are mimicked in the overlying succession as structures to a large extent formed through compactional draping of strata (Reasoner and Hunt, 1954b; Jones, 1961a; Maycock, 1967; Christopher *et al*, 1971). An easterly trending dissected cuesta and dip slope on Mississippian limestones is flanked to the north and south by broad subsequent valleys. Obsequent valleys are cut down into the underlying Devonian strata, and buttes and mesas of outlying Mississippian rock occupy the southern part of the northern subsequent valley. Resequent valleys join the southern subsequent, which latter separates the Mississippian cuesta from a similar feature, eroded along the east-west edge of the Jurassic sediments replacing Mississippian rocks southward at the pre-Cretaceous surface. The pre-Cretaceous cuestas and subsequent valleys give rise to systems of irregular domes and broad troughlike features, respectively, at the top of the Mannville sequence and within the Colorado succession, notably at correlation surfaces marking the boundaries of the Viking Formation (Jones, 1961a). Both obsequent and resequent valleys give rise to prominent synclines in the Colorado sequence. A series of low mesas, eroded along the edge of the Devonian Birdbear Formation, gives rise to low domes on Lower Colorado correlation surfaces. The existence of some control of sub-Cretaceous palaeotopography over the sedimentation of regressive, siliciclastic deposits is strongly suggested by the localized occurrence of Viking Chert above deeply incised, sub-Cretaceous valley forms. Furthermore, anomalously thick Viking sandstones to the south of the Dodsland-Hoosier production locale appear also to be causally related to underlying valley forms at the sub-Cretaceous unconformity. This may be demonstrated by comparing Fig. 39 with Fig. 17 of Christopher (1974, p. 47).

Eastern Shore-to-Basin Transition

The main basement linear of the eastern Colorado shelf is the Meadow Lake escarpment, which takes the form of an anticlinal nose trending northeastwards from the intersection of Latitude 53° 45′ and the Fourth Meridian. This structure may have arisen through two separate episodes of faulting along a basement fracture zone, possibly in Late Cretaceous time (Hees, 1958). It is noteworthy that the thicknesses of both the St. Walburg Sandstone and the Flotten Lake Sand increase towards the arch, that each unit undergoes a decrease in the proportion of intercalated mudstone in the same direction and that the intervening tongue of Big River shales and mudstones is absent in the vicinity of Meadow Lake. These facts may show the existence of the escarpment as a positive topographic feature during sedimentation.

Northwesterly-trending lineaments on the Devonian, east of Lloydminster, defined by a broad trough and complementary monocline to the northeast, are reflected in structures at the Mannville top (Christopher *et al*, 1971), as is a broad, positive relief feature at Beacon Hill. The latter, however, appears also to be related to positive relief at the Precambrian surface (Agarwal, 1960), deduced from aeromagnetic and seismic data.

The possibility of solution-generated collapse with related depression of the depositional surface during Lower Colorado sedimentation on the eastern shelf is suggested by localized thickening of the Lower Colorado succession. This takes the form of an increase in thickness of the St. Walburg Sandstone and underlying tongue of Big River shales and mudstones above a northwest-trending depression of the Mannville top. This linear sink at the Mannville top may be related to localized solution along the northern edge of the Prairie Evaporite.


O
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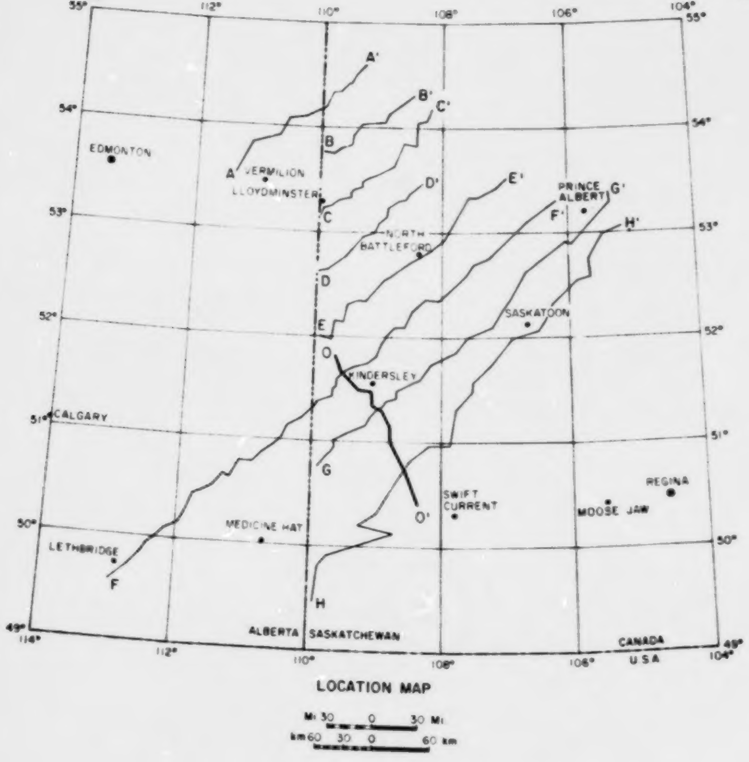
24
STRATIGRAPHIC DATUM BASE OF SECOND WHITE-SPECKLED SHALE
FISH-SCALE MARKER
BIG RIVER FM
BIG RIVER FM.
VIKING FM
JOLI FOU FM
SPINNEY HILL SANDSTONE
PENSE FM.
VIKING
JOLI FOU MUDSTONE
SPINNEY HILL SANDSTONE


114°
112°
110°
108°
106°
104°
55°
54°
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49°
EDMONTON
VERMILION
LLOYDMINSTER
NORTH BATTLEFORD
PRINCE ALBERT
SASKATOON
KINDERSLEY
CALGARY
MEDICINE HAT
LETHBRIDGE
SWIFT CURRENT
MOOSE JAW
REGINA
ALBERTA
SASKATCHEWAN
CANADA
U.S.A.
A
A'
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LOCATION MAP
Mi 30 0 30 Mi
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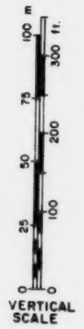
No	WELL NAME	LOCATION	K.B.
1	Can Seab'd Canso Fusilier 7-1-33-27	7-1-33-27W3	2403'
2	Canso Canadian Seaboard 6-29	6-29-32-26W3	2333'
3	Canada Southern Dewar 6-14	6-14-31-26W3	2327'
4	Teo No. 1	2-28-30-25W3	2270'
6	Phillips Husky Clover No. 1	13-32-29-24W3	2206'
7	Kewanee Kindersley 6-14-29-24	6-14-29-24W3	2256'
8	Kewanee Kindersley 6-12-29-23	6-12-29-23W3	2273'
9	Phillips Husky Turvin No. 1	6-19-28-22W3	2310'
10	Sangren No. 1	7-29-27-22W3	2336'
11	Imperial Netherhill 11-17-27-21	11-17-27-21W3	2318'
12	Phillips Husky Dome Snipe No. 1	7-28-26-21W3	2283'
13	Imperial Centrefield 13-10-26-21	13-10-26-21W3	2258'

No	WELL NAME	LOCATION	K.B.
14	Phillips Husky Eston No. 1	7-29-25-20W3	2242'
15	Phillips Husky Guth No. 1	11-29-24-20W3	2117'
16	Fairdale No. 1	8-29-23-20W3	2128'
17	Abbey Crown No. 1	3-18-22-19W3	2095'
18	Cabri Crown No. 1	1-23-20-19W3	2021'
19	Cabri 1-30	1-30-19-18W3	2152'
20	Seaboard TW Cabri Cr. 3-9-19-18	3-9-19-18W3	2159'
21	Socony Woodley Southern Cabri 22-1	1-22-18-18W3	2347'
23	M.O.W.S. Cabri 7-1-18-18	7-1-18-18W3	2329'
24	M.U.S. Cantuar 2-21-16-17	2-21-16-17W3	2411'


m
ft.
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25
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75
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100
200
300
VERTICAL SCALE

Figure 39 — Northwest-southeast stratigraphic cross-section O-O' of Lower Colorado strata between the Can Seaboard Canso Fusilier 7-1-33-27 (Lsd 7-1-33-27W3) and MUS Cantuar 2-21-16-17 (Lsd 2-21-16-17W3) wells.

Abstract

The Colorado Group (middle Albian to Santonian) of the Canadian Great Plains was deposited in an epeiric sea, which occupied an asymmetrically subsiding structural basin, located to the east of the rising Cordilleran mountain belt. In Saskatchewan, Colorado lithologies reflect two largely transgressive phases of dominant mud deposition and an intervening regressive phase, represented by a northeastward-thinning wedge of conglomerates and sandstones, which grade into fine-grained deposits. The Colorado succession is divided into upper and lower subgroups at the disconformity marking the base of the lower of two widespread calcareous marker units, the Second White-Speckled Shale (Turonian). Fluctuation in subsidence relative to sedimentation produced shifting spatial relationships between two major shelf areas, which were sites of sand deposition (notably in Lower Colorado time) and a central basin where muds were laid down: the rapidly subsiding western shelf received large volumes of siliciclastics from the rising Cordilleran uplifts, whereas the comparatively quiescent eastern shelf was supplied with relatively minor quantities of sediment from the Precambrian Shield. The chief agents of sediment dispersal were storm-surge-augmented tidal currents that produced large-scale sand ridges and tidal-channel deposits.

The Joli Fou Formation reflects the early transgression and consists of sporadic, thin reworked relict deposits succeeded by fine-grained, shaly, glauconitic sandstones of an estuarine delta (Spinney Hill Sandstone), which are overlain by and grade southwestward into non-calcareous mudstones. The dominant biofacies is vital-heterostrate, with ostracodes, agglutinating Foraminifera, bryozoans, pelecypods, disciniscid and lingulid brachiopods and ophiuroids, in addition to death-assemblages of radiolarians and diatoms in phosphorite nodules and current-formed accumulations of fish-skeletal debris.

The Viking Formation consists of conglomerates and shaly sandstones in dominantly coarsening-upward sequences, deposited mostly during the regression on the western shelf as nearshore sand bodies and tidal sand ridges upon a thin layer of reworked, relict gravels. The Viking sandstones incorporate lethal-heterostrate biofacies, comprising exotic debris and reworked Joli Fou fossils, and vital-heterostrate biofacies. The latter are characterized by trace-fossil assemblages of associated, second-order biofacies, which include deep, vertical, tubular burrows (nearshore), deep *spreite* burrows (proximal shelf), and shallow *spreite* burrows, associated with horizontal, branched forms (distal shelf). Low-permeability, bioturbated, shaly sandstones constitute the main reservoir lithology of the Kindersley production district; biogenic destruction of primary layering has largely eliminated the shale breaks which form the numerous reservoir heterogeneities commonly associated with sandstones and conglomerates of higher permeability. The Flotten Lake Sand displays southwestward diminution of grain size and thinning along the erosional edge of the Colorado sequence. The transgressive Big River Formation is largely made up of non-calcareous basin and distal-shelf mudstones and incorporates the widespread, northeastward-thinning Fish-Scale-Marker, which contains abundant sand-grade fish-skeletal debris as graded beds. Below the marker, the Big River mudstones pass northeastward into the fine-grained, kaolinitic, shaly St. Walburg Sandstone. Above, the Big River mudstones contain abundant megaspores, frequently tightly packed on bedding planes. The boundary between Early and Late Cretaceous strata is at or near the base of the marker unit.

The Sweetgrass arch appears to have influenced Lower Colorado sedimentation across the western shore-to-basin transition, principally by limiting the eastward dispersal of regressive sandstones. The eastern shelf coincided with a structural platform, approximately delineated in the south by the modern North Saskatchewan River.

The Viking oil and gas reservoirs occupy the updip pinchouts of nearshore and proximal-shelf sandstones on the Sweetgrass arch, where drape folds in the Colorado succession mimic cuesta and valley forms at the sub-Cretaceous unconformity, notably along the northern limits of subcropping Jurassic and Mississippian strata respectively. The capping lithologies of the reservoirs are frequently thin layers of strongly indurated sandstone, cemented by calcite, siderite and subordinate pyrite. These are located at the tops of coarsening-upward sequences, usually a few metres below the contact with the shale. These cement-rich layers are the permeability barriers, which, to a large extent are responsible for the low reservoir pressures commonly associated with Viking production. Hydrocarbon prospects lie in the nearshore and proximal-shelf Viking facies, occupying little explored domal features immediately south of the Dodsland-Hoosier production district. Distal-shelf Viking facies of the Unity-Vera area remain prospective for relatively small accumulations of natural gas. The St. Walburg Sandstone and Flotten Lake Sand are also prospective for gas in the western part of the eastern shelf, where local dip reversals have resulted from collapse of strata following solution and removal of Middle Devonian evaporites. The best prospects in the Spinney Hill Sandstone are also associated with solution-generated collapse structures in the distal-shelf facies of the unit.

Economic Geology

Current Petroleum Production

Petroleum production from Lower Colorado strata in the Province as a whole is confined to the Viking Formation of the west (Table 5). The principal reservoir rocks are sandy type-II elements with subordinate mudstone interlayers and, more importantly, sandy type-III elements, comprising fine-grained, glauconitic sandstones with thin, discontinuous mudstone interlayers. Of less frequent occurrence, but of great economic importance, are fairly well sorted, coarse-grained type-IV elements and type-V elements with high porosity and permeability, as in the Smiley-Dewar "Viking chert" pool and the Plato pool. API gravities of oil from Viking reservoirs in west-central Saskatchewan are in the range of 30° to 36° (Charbonnier *et al*, 1969a); a somewhat wider range of API gravities is encountered in the Viking Formation of Alberta (Charbonnier *et al*, 1969b). In general, Viking crude oils are predominantly paraffinic with low weighted average contents of sulphur, and formation waters of the production area are characterized by a relatively low chloride content of less than 18,900 mg/L (Hitchon, 1964). Viking reservoirs of the Dodsland-Hoosier pool complex are characterized by a relatively high interstitial water saturation of 40 to 60 per cent. The water is usually non-producible and this is thought to result from adsorption to thin, discontinuous mudstone interlayers of type-III elements (cf. Evans, 1970, p. 485). Farther south, increase in thickness of the formation, in part due to the occurrence of an uppermost lenticle of clean, well sorted sandstone, is accompanied by the appearance of bodies of free water and progressive southerly increase in elevation of the gas-water contact.

Two different origins for the Viking crude oils are conceivable:

(1) Hydrocarbons, driven out of Big River and Joli Fou muds undergoing compaction within the Alberta Basin, migrated eastward and northeastward to be trapped and concentrated as pools of light-gravity crude oil in structural undulations of the Viking Formation. These developed coevally, also through compaction, in the region of Viking sand attenuation, possibly before the formation acquired a southerly, Laramide tilt. With increased compaction Viking sandstones became to a large extent hydraulically isolated between considerable thicknesses of Colorado shales, which served to retain the trapped hydrocarbons.

(2) A genetic relationship may exist between the light crude oils of Viking reservoirs and the heavy crude oils of the Birdbear Formation (12° API) in Twp 31, Rge 26W3, the Bakken Formation (13° to 15° API) of the Buffalo Coulee, Coleville and North Hoosier fields, the Deville Formation (10° to 18° API) in Twp 31, Rge 28W3, and the basal Mannville Group (14° to 17° API) of the Alsask and North Hoosier fields. The light oils in Viking reservoirs may be of Palaeozoic ancestry and represent hydrocarbons which moved through the Joli Fou shales under osmotic (?) pressure, while the heavy oils in the vicinity of the pre-Cretaceous unconformity may be regarded as distillation residua.

Support for origin (1) comes from the north-easterly direction of flow for formation waters of the Viking Formation in western Saskatchewan (Hill *et al*, 1961, Fig. 2, p. 44). Similarity in variation of chloride content in formation waters of the Mannville succession and the Viking Formation respectively (Hitchon, 1964, Fig. 15-34, Fig. 15-36, p. 215) suggests the possibility of fluid flow across formation boundaries and hence would be in accord with origin (2).

FACIES BELT PHASE OF DEPOSITION	INNER BELT	CENTRAL BELT		MARGINAL BELT
LATE TRANSGRESSIVE PHASE	**Fish-Scale Marker** no production, in Saskatchewan no drill stem tests, but production of non-associated natural gas in SE Alberta; production of light crude oil at Barons Field (Twp 12, Rg 23, W4 Mer)	**St. Walburg Sandstone** no production; sequence virtually untested		
REGRESSIVE PHASE	**Viking Formation** nearshore deposits production of non-associated natural gas from type-IV elements in structural-stratigraphic traps located along northern edge of nearshore deposits (Bayhurst pool) structure controlled by relief of pre-Cretaceous surface especially above eroded Jurassic edge	**Viking Formation** proximal shelf deposits: production of non-associated and associated natural gas from type-III and II elements (Brock, Coleville-Smiley, Dodsland, Glidden, Greenan, Hoosier, Lucky Hills, Milton, Whiteside), light crude oil from type-V elements (Smiley-Dewar pool) and type-III and-II elements Avon Hill, Dodsland, Eureka, Plato, Smiley-Dewar Whiteside).	distal shelf deposits: production of non-associated natural gas from type-III and-II elements at Unity. All traps structural-stratigraphic, controlled by relief at pre-Cretaceous surface. Showings very common in proximal deposits; locally common in distal deposits (*e g* Unity-Vera district)	**Flotten Lake Sand** no production, sequence untested
EARLY TRANSGRESSIVE PHASE	**Joli Fou mudstones** no production in Saskatchewan, but production of medium-gravity crude oil (24° API) and non-associated natural gas from Cessford Sand in SE Alberta (Cessford field, Twp 24 and 25, Rge. 12, W4 Mer.)	**Spinney Hill Sandstone** no production, few drill stem tests, several showings of natural gas recorded in both proximal and distal fluvio-marine deposits, *e g* gas-cut salt water from 1981 to 1991 ft in Liberal Canada Southern New Devon Skyline No. 2 (3-6-37-16W3)		

Table 5 — Current hydrocarbon production and showings related to depositional systems of Lower Colorado sediments, west-central Saskatchewan.

Hydrocarbon Potential

Viking Formation

Rapid well completion and relatively low dry-hole and completion costs, reflecting the shallow depth of pay in the range 664.5 m to 731.5 m within the production area, as well as numerous shows of oil and gas, to a large extent offset the variable and frequently poor reservoir quality of Viking lithologies (Table 6). Regardless of origin, the distribution of particular formation fluids seems to be largely a function of (1) lithologic change within the Viking and (2) distribution of large-scale structural features mimicking the pre-Cretaceous palaeotopography.

In west-central Saskatchewan, the distribution of production and hydrocarbon shows suggests that the northerly limit of good Viking prospects is the belt of marked Viking sand attenuation, parallel to the edge of the Mississippian. It is probable that further development of this production area will proceed by extensions of the principal pools and the new-pool wildcats south of the main pool complex. In considerations of prospective areas, undue weight should not be placed on clusters of abandoned dry holes drilled to the Viking Formation. This point is illustrated by the Plato oil field (Fig. 40) discovered in 1968 and now comprising more than 50 oil wells, drilled on an 80-acre spacing. The field area is surrounded by dry holes, drilled and abandoned in the mid-1950's.

North of the belt of marked sand attenuation, Viking reservoir sands of good quality appear to be confined to relatively thin, fine-grained scattered sand bodies, associated with highs on the pre-Cretaceous surface. A

FACIES BELT / PHASE OF DEPOSITION	INNER BELT	CENTRAL BELT	MARGINAL BELT
LATE TRANSGRESSIVE PHASE	Fish Scale Marker may be prospective for natural gas in structures above the Jurassic subcrop, where unit attains greatest thickness in area	type-III and -IV sequence elements of the St. Walburg Sandstone are of good reservoir potential and should be prospective for natural gas where the Mannville Group constitutes a prime target, *i.e* on structures reflecting features at the pre-Cretaceous surface, *c.f.* salt-solution features and irregularities of Precambrian surface; increasing probability of geological success and economic failure[1] south-and southwestward	
REGRESSIVE PHASE	type-IV and subordinate type-III elements of Viking Formation prospective for gas along northern edge of nearshore deposits; geological successes likely to be economic successes	type-III,-II and possibly -V elements of Viking proximal-shelf deposits prospective for light crude oil and natural gas on structures south of Dodsland-Hoosier trend; muddy type-IV and-II elements of distal-shelf deposits prospective for natural gas over pre-Cretaceous mesas and cuestas at erosional edges of Devonian formations; increasing probability of geological success and economic failure[1] north-and northeastward	Flotten Lake Sand appears to be of good reservoir potential and may be prospective for natural gas over salt-solution structures and positive relief features of the Precambrian surface; increasing probability of geological success and economic failure[1] south-and southwestward
EARLY TRANSGRESSIVE PHASE	Cessford Sand prospective for hydrocarbons south of study area?	type-II, -III and -IV elements of both proximal and distal fluviomarine deposits in the Spinney Hill Sandstone prospective for natural gas; *c.f.* structures above erosional edges of Devonian formations, salt-solution features, irregularities of the Precambrian surface; increasing probability of geological success and economic failure[1] south-and southwestward	

[1] usually localized thick developments of tight, fine-grained sandstones, showing only minor improvement in reservoir quality, though associated with structures, which might merit drilling.

Table 6 — Hydrocarbon potential related to depositional systems of Lower Colorado sediments, west-central Saskatchewan.

noteworthy example is the Viking sand of the Unity gas field, the production from which supplements that of the Mannville Unity sand.

St. Walburg Sandstone

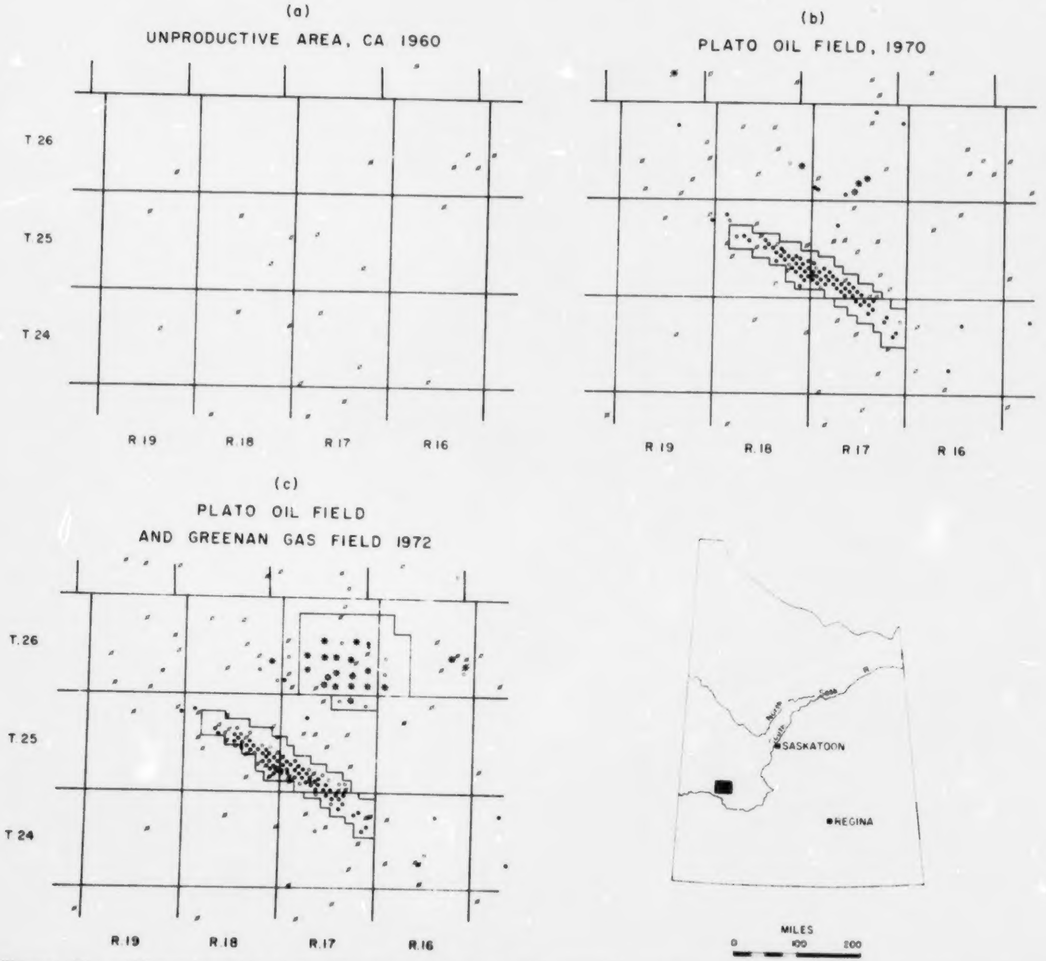
The St. Walburg Sandstone is prospective for natural gas (1) on domal drape folds, located above mesas at the sub-Cretaceous unconformity, and (2) along the southern pinch-out of the unit, especially where drape-folding over sub-Cretaceous topographic highs or solution-generated collapse of strata have produced local reversals of dip. The best prospects appear to lie between Longitude 108 ° and the Fourth Meridian, in the vicinity of the northern limit of the Prairie Evaporite. The same structures may also yield natural gas from Mannville reservoirs.

Flotten Lake Sand

The Flotten Lake Sand is also thought to be prospective for natural gas in the types of trap considered above for the St. Walburg Sandstone and in the same general area.

Spinney Hill Sandstone

The Spinney Hill lithologies, considered to be most prospective for hydrocarbons in west-central Saskatchewan, are of the distal facies and occupy an area, characterized by extensive solution-generated disruption of strata, extending from the southeastern margin of the eastern shelf to the southern perimeter of the study area between 107° and 108 ° of longitude. The unit may also be prospective in the eastern part of the Kindersley production district, over the same structures, which have yielded hydrocarbons from the Viking Formation.



(a) UNPRODUCTIVE AREA, CA 1960

(b) PLATO OIL FIELD, 1970

(c) PLATO OIL FIELD AND GREENAN GAS FIELD 1972

Figure 40 — Oil exploration in the Plato district, west-central Saskatchewan. Ranges are west of the Third Meridian.

Rationale of Exploration for Lower Colorado Targets

Parts of west-central Saskatchewan, where hydrocarbon prospects in the Lower Colorado succession are considered good, are outlined below.

Since current petroleum production from the Viking Formation is obtained where rocks of improved reservoir quality wedge out in structures reflecting relief features of the buried pre-Cretaceous erosion surface, it follows that a worthwhile search strategy should be directed toward Viking type-IV elements along the northern edge of the nearshore deposits and also Viking type-II and type-III elements of the proximal shelf sequence south and east of the Dodsland-Hoosier trend.

Sandstones of the distal shelf, associated with Devonian mesas, especially along the edge of the Birdbear Formation, also may prove to be prospective. Furthermore, the existence of current production from the Birdbear, Bakken and Deville Formations and basal Mannville sands in west-central Saskatchewan (White, 1969) and the occurrence of numerous shows of oil and gas in the Viking and Mannville sequences, as well as in Palaeozoic limestones, suggests that the region is endowed with multiple petroleum prospects, in a variety of traps at shallow depths (Simpson, 1970b).

Lower Colorado sands other than those of the Viking Formation are for the most part untested. The most effective prospecting approach is likely to be one which combines testing of Colorado sands with exploration for Mannville targets, since both are affected by structures arising through draping of pre-Cretaceous relief. By analogy with structures related to current production from the Mannville sequence in southwestern Saskatchewan, at Lloydminster and at Beacon Hill, it follows that future production is likely to be associated with linear troughs and escarpments at the pre-Cretaceous surface. In the north of the study area, positive relief features of the Precambrian erosion surface may be of considerable importance and, in this connection, it is of considerable interest to note that current production of gas from Mannville sediments, which includes that at the Beacon Hill gas field, is obtained along a prominent trend of Precambrian highs, indicated by aeromagnetic and seismic work (Agarwal, 1960). Further drilling along this trend may prove rewarding. Likewise, the possible structural significance of magnetic domains in the area west of Buffalo Narrows (Wallis, 1970), and their southerly extensions, merit further investigation.

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Plates I to XXV

Plate I

(Horizontal scale on all figures is of length 0.1 mm; cpl = cross polarized light, ppl = plane polarized light)

Figure 1 — Protoquartzite with calcite cement; cpl; Spinney Hill Sandstone, 31.2 m, D.N.R. Big River No. 5 (Lsd 2-22-58-9W3).

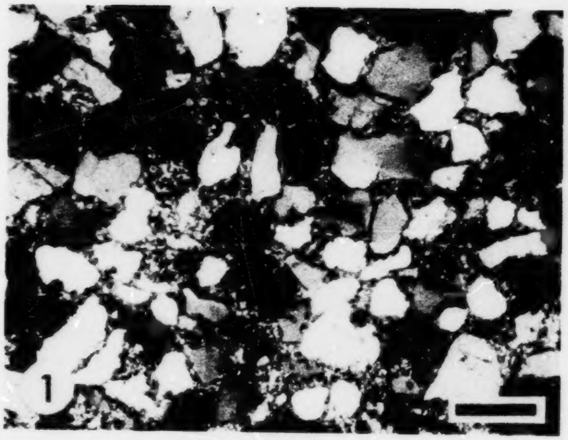
Figure 2 — Protoquartzite with calcite cement, showing relatively coarse grains of polycrystalline quartz; cpl; Spinney Hill Sandstone, 198.3 m, D.N.R. Big River No. 6 (Lsd 5-10-55-7W3).

Figure 3 — Glauconitic subgreywacke; cpl; Spinney Hill Sandstone, 770.4 m, Imperial Netherhill 11-17-27-21 (Lsd 11-17-27-21W3).

Figure 4 — Glauconite pellet with random microcrystalline internal structure; crystals of surrounding calcite cement radiate from pellet; cpl; Spinney Hill Sandstone, 666 m, Ceepee Broadacres 13-13 (Lsd 13-13-35-21W3).

Figure 5 — Calcareous protoquartzite with abundant chert grains; ppl; Viking Formation, 700.7 m, Canus et al N. Verendrye 12-32-28-23 (Lsd 12-32-28-23W3).

Figure 6 — Subgreywacke; cpl; Viking Formation, 680.3 m, Oliphant NWRCo Gorefield 7-22-24-26 (Lsd 7-22-24-26W3).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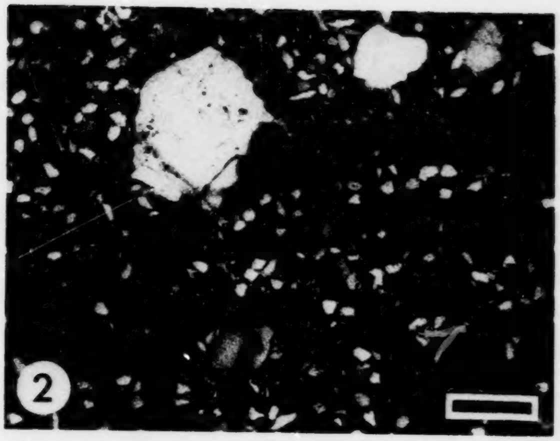
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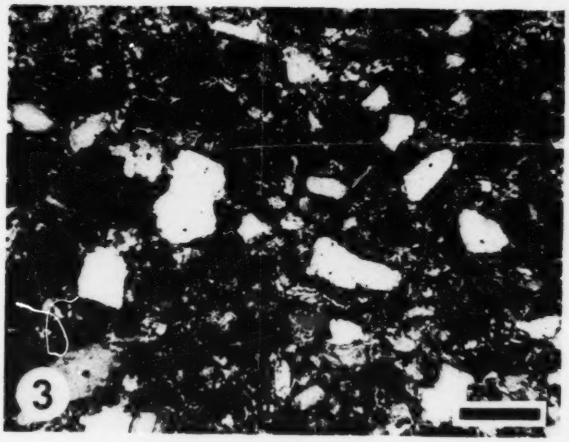
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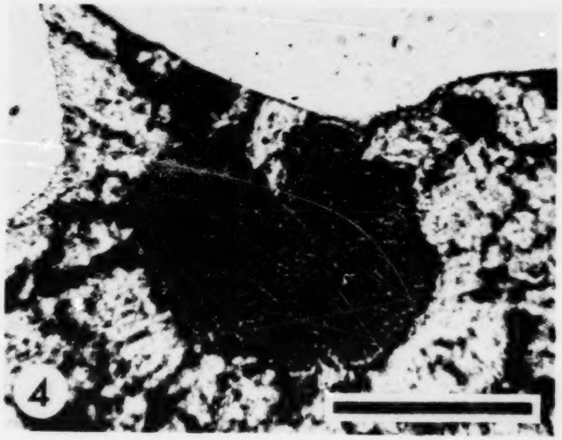
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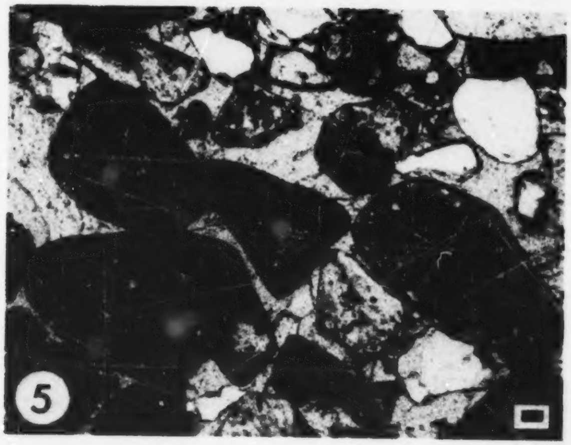
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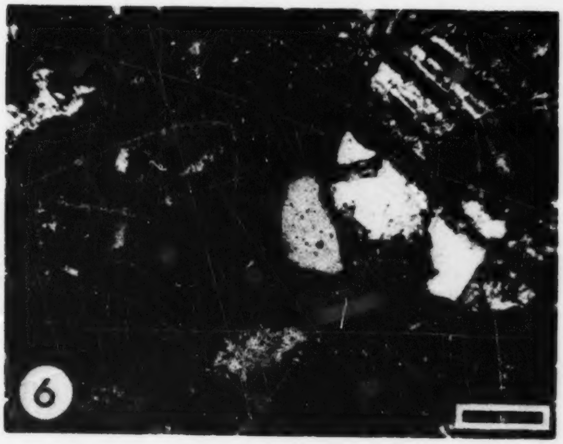
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Plate II

(Horizontal scale on all figures is of length 0.1 mm; cpl = cross polarized light, ppl = plane polarized light)

Figure 1 — Subgreywacke; cpl; St. Walburg Sandstone, 344.4 m, Cdn Seaboard Turtle L 4-16-55-18 (Lsd 4-16-55-18W3).

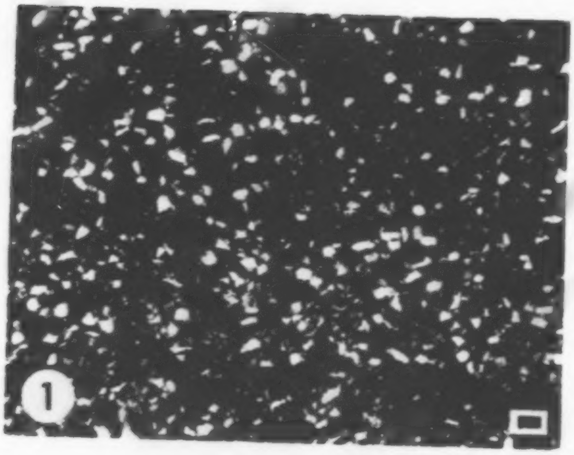
Figure 2 — Detail of Fig. 1.

Figure 3 — Radial cross-section of remanié phosphatized plant tissue, occurring as cobble in thin conglomeratic layer; arrow indicates annual ring; ppl; Viking Formation, 645.3 m, Ceepee Dukesbury 13-18 (Lsd 13-18-34-21W3).

Figure 4 — Oblique longitudinal cross-section of remanié phosphatized plant tissue; other data as for Fig. 3.

Figure 5 — Pelecypod-foram biosparite containing abundant calcite from the prismatic layer of *Inoceramus* (arrow); cpl; Second White-Speckled Shale, 105 m, D.N.R. Flotten Lake No. 2 (Lsd 4-10-65-17W3).

Figure 6 — Pelecypod-foram biosparite with abundant calcite-filled tests of pelagic Foraminifera (arrow); cpl; Second White-Speckled Shale, 532.6 m, Marvel Kamalta Plato 14-7-25-17 (Lsd 14-7-25-17W3).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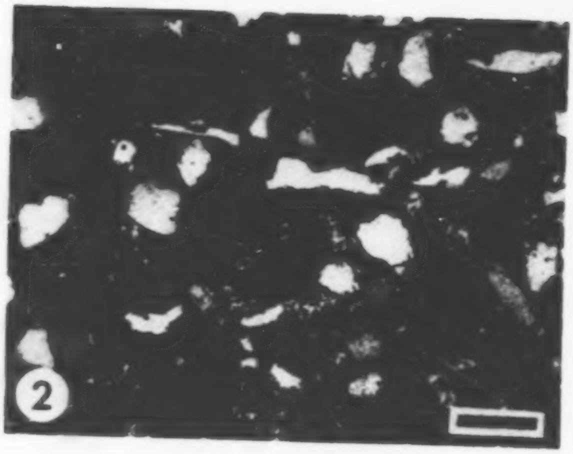
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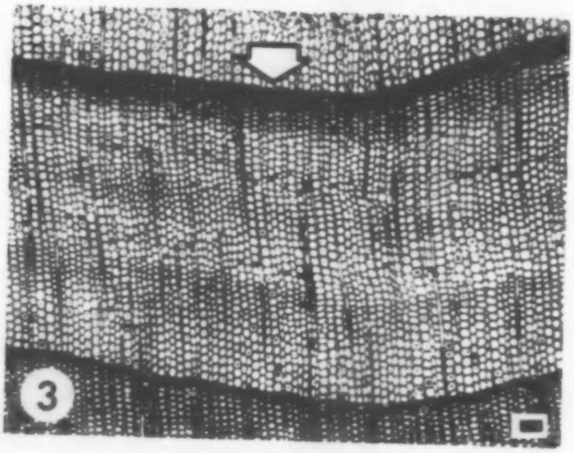
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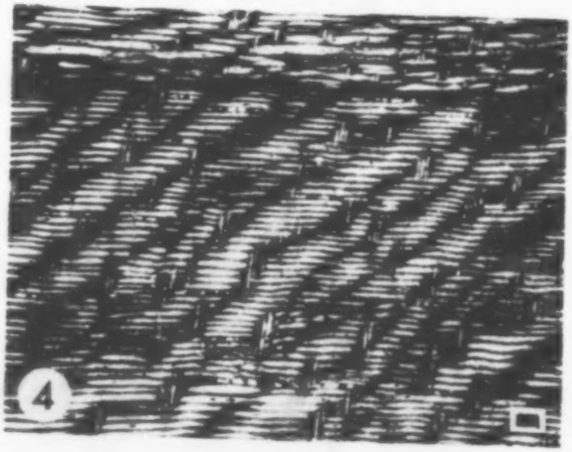
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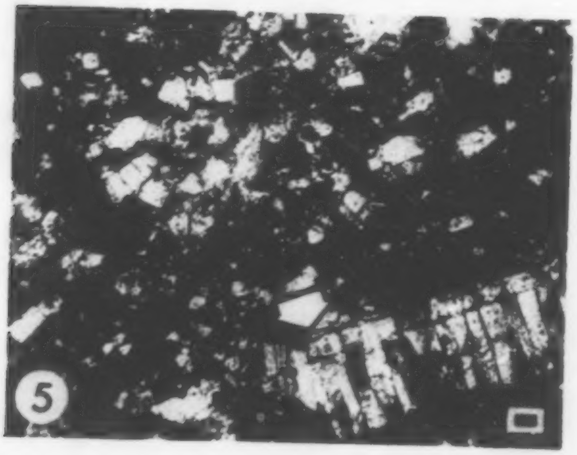
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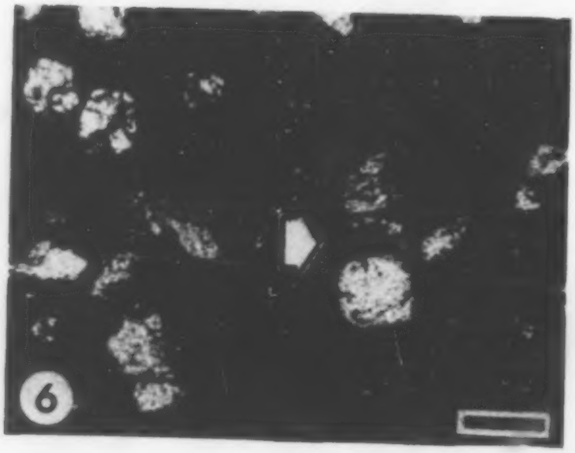
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Plate III

(Horizontal scale on all figures is of length 0.1 mm; cpl = cross polarized light, ppl = plane polarized light)

Figure 1 — Biogenic phosphate layer, made up of fish scales, vertebrae and bone fragments with scarce sand-grade quartz grains; ppl; Fish-Scale Marker of Big River Formation, 417.6 m, Lloydminster No. 5 (Lsd 9-6-49-28W3).

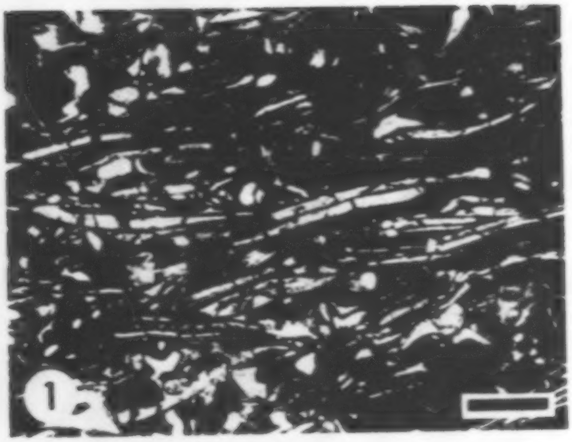
Figure 2 — Siderite cement (arrow) in well indurated, fine-grained sandstone; ppl; Viking Formation, 736.5 m, Cabeen Expl Whiteside 11-17 (Lsd 11-17-30-25W3).

Figure 3 — Calcareous protoquartzite with abundant chert grains; frequently hollow, globular bodies interpreted as relict hydrocarbon droplets float in calcite cement filling pores and also make flat contacts with detrital grains (circle); cpl; Viking Formation, 700.7 m, Canus et al N. Verendrye 12-32-28-23 (Lsd 12-32-28-23W3).

Figure 4 — Probable relict hydrocarbon droplet making wetting contact (arrow) with flat boundary of chert grain; rounded edge of droplet in contact with calcite cement; cpl; other data as for Fig. 3.

Figure 5 — Probable relict hydrocarbon droplets making wetting contact (arrow) with chert grains; droplets with thin skin visible at rounded peripheries; cpl; other data as for Fig. 3.

Figure 6 — Hollow droplets with thin skin visible at rounded peripheries; ppl; other data as for Fig. 3.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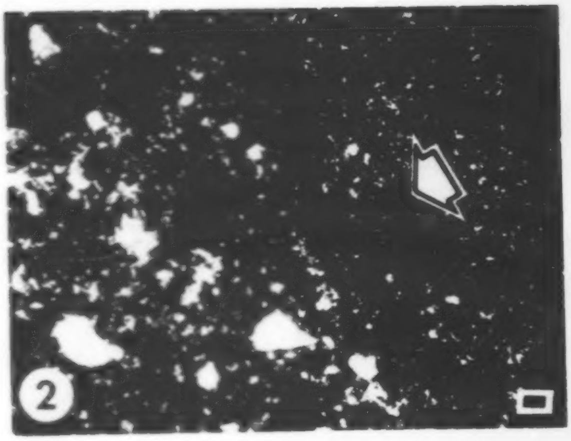
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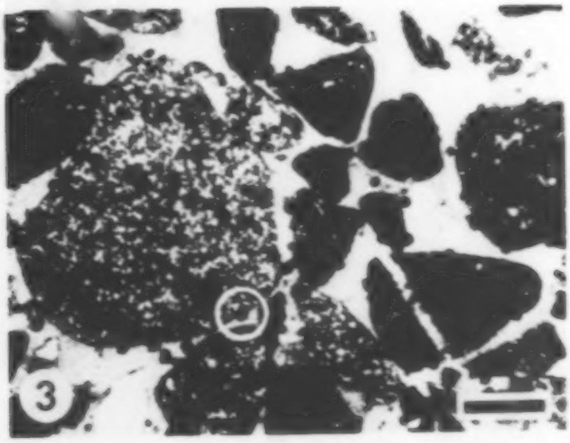
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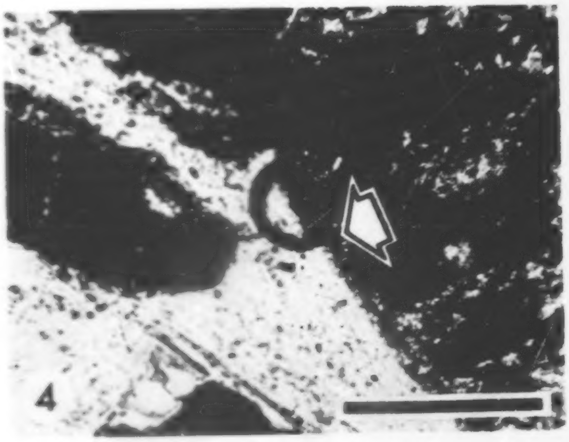
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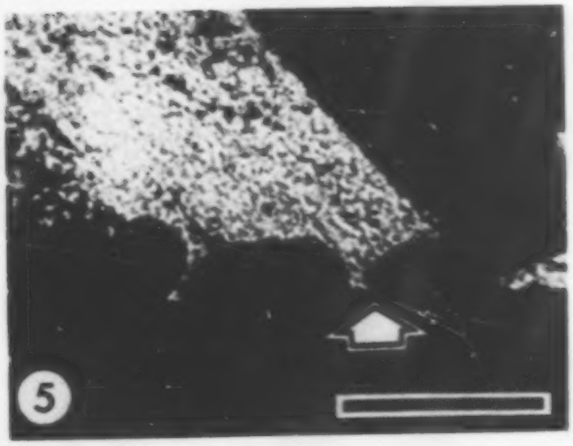
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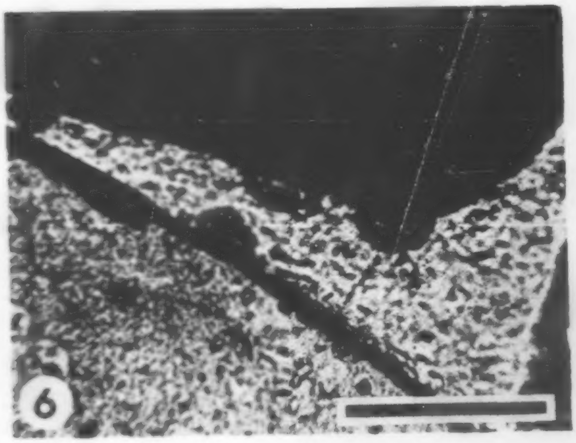
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Plate IV

(Horizontal scale on all figures is of length 0.1 mm; cpl = cross polarized light, ppl = plane polarized light, rl = reflected light)

Figure 1 — Siderite crystals (arrow) lining walls of central void of spherulite in ferruginous silty mudstone; crystals enclosed in mixture of ankerite and siderite; ppl; Viking Formation, 674.7 m, Socony Sohio Richlea 7-11 (Lsd 7-11-26-19W3).

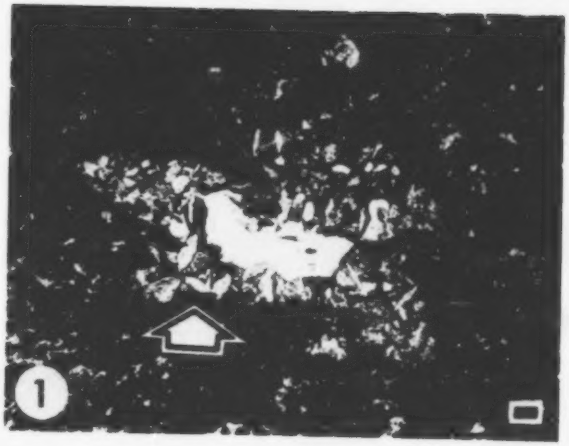
Figure 2 — Curved, radiating crystals of siderite (arrow) forming peripheral part of spherulite in ferruginous silty mudstone; contact with mudstone rich in ankerite and siderite shown; ppl; other data as for Fig. 1.

Figure 3 — Oolite composed of concentric siderite layers enclosing quartz grains (arrow) and with calcite and siderite cements; cpl; Joli Fou Formation, 786.4 to 789.4 m, (well cuttings), Phillips Pete Noremac No. 1 (Lsd 6-29-24-22W3).

Figure 4 — Pyritized ooids with quartz grains (arrow) as nuclei; ppl; Joli Fou Formation, 701 to 704.1 m, (well cuttings), Sohio Peter Wartime No. 1 (Lsd 2-14-26-17W3).

Figure 5 — Biogenic phosphate, consisting of fragmental fish bones and teeth, and nodular phosphate cemented by pyrite (light grey); note corrosion of phosphate by pyrite; rl; Joli Fou Formation, 820.5 m, Stanolind Prelate Crown No. 1 (Lsd 9-34-19-24W3).

Figure 6 — Data as for Fig. 5.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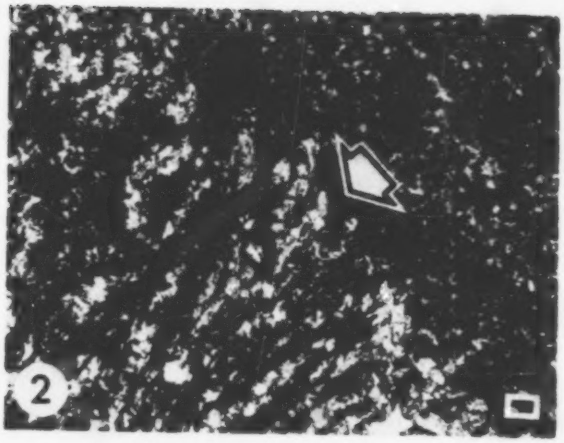
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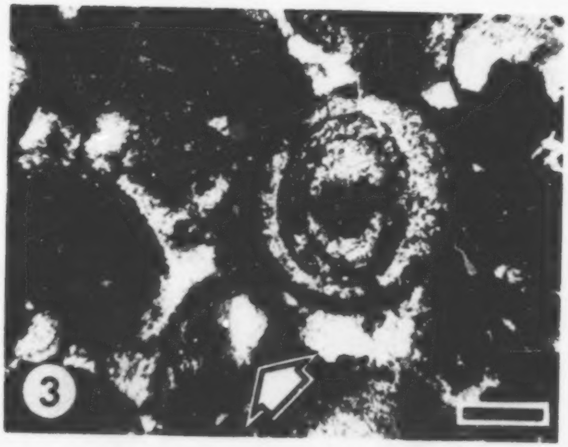
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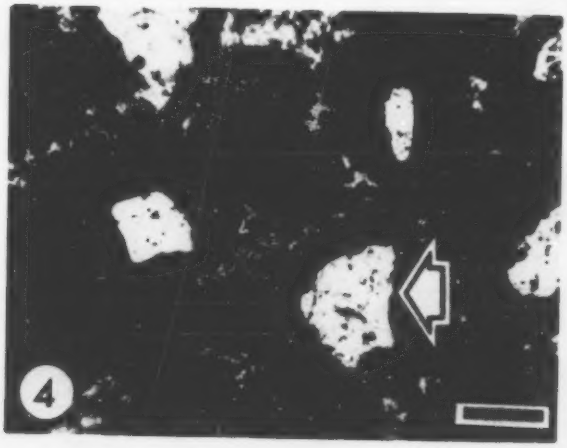
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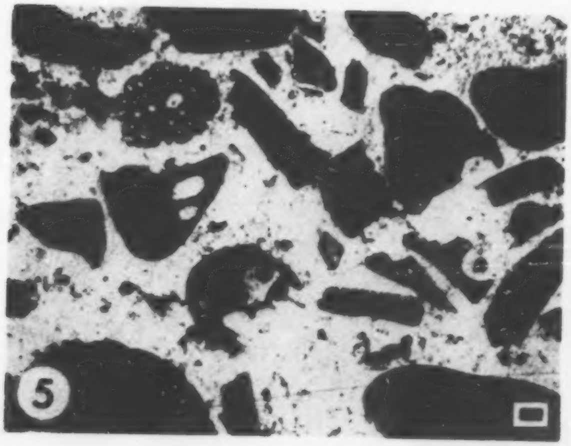
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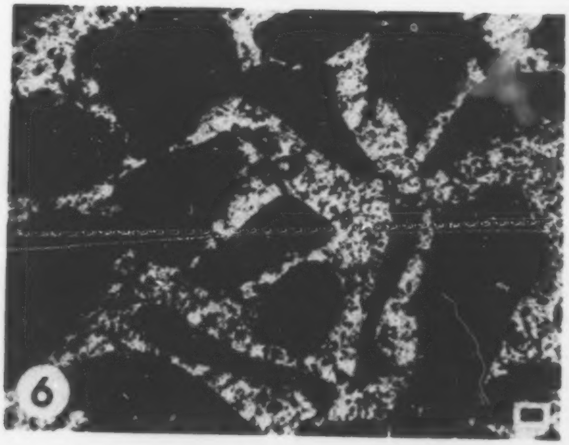
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Plate V

(Horizontal scale on all figures is of length 0.1 mm; cpl = cross polarized light, ppl = plane polarized light, rl = reflected light)

Figure 1 — Calcite crystals from prismatic layer of *Inoceramus* (arrow) and biogenic phosphate cemented by pyrite (light grey); rl; Joli Fou Formation, 820.5 m, Stanolind Prelate Crown No. 1 (Lsd 9-34-19-24W3).

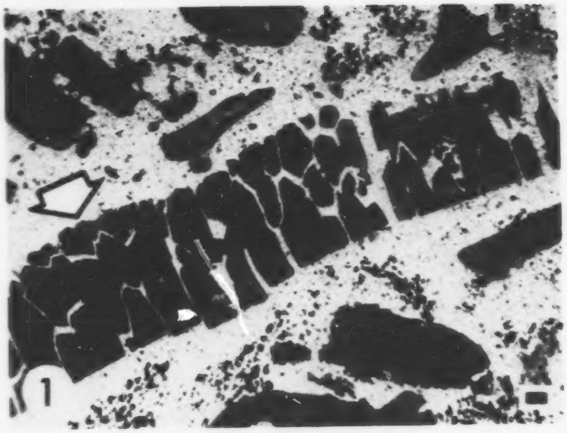
Figure 2 — Random orientation of floccules (arrow) making up phosphate nodule; ppl; Joli Fou Formation, 621.5 m, Ceepee Reward 4-28 (Lsd 4-28-38-24W3).

Figure 3 — Detail of ripple-drift cross-lamination in phosphate nodule, showing ordered arrangement of phosphate floccules (lower arrow) and quartz grains (upper arrow) in bipartite laminae; ppl; Joli Fou Formation, 463.4 m, Duval Saskatoon 6-18-36-6 (Lsd 6-18-36-6W3).

Figure 4 — Phosphate floccule in nodule displaying ripple-drift cross-lamination; other data as for Fig. 3.

Figure 5 — Radiolarians (arrows) preserved in phosphate nodule; intraformational conglomerate; ppl; Joli Fou Formation, 726.9 m, Imperial Dewar 7-15V-31-26 (Lsd 7-15-31-26W3).

Figure 6 — Phosphorite forming part of phosphate-impregnated sandstone cobble belonging to intraformational conglomerate; ppl; Spinney Hill Sandstone, 702.6 m, Ceepee Daniels 6-29 (Lsd 6-29-31-19W3).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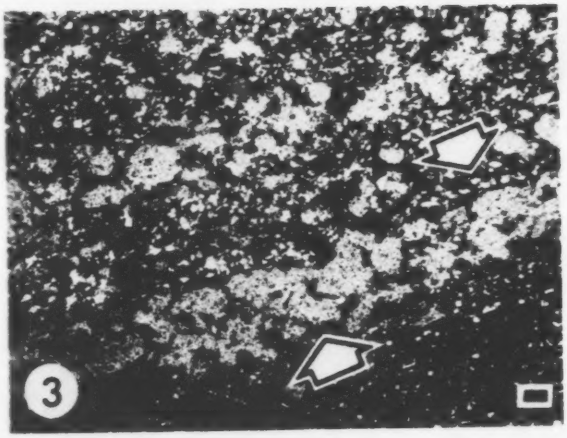
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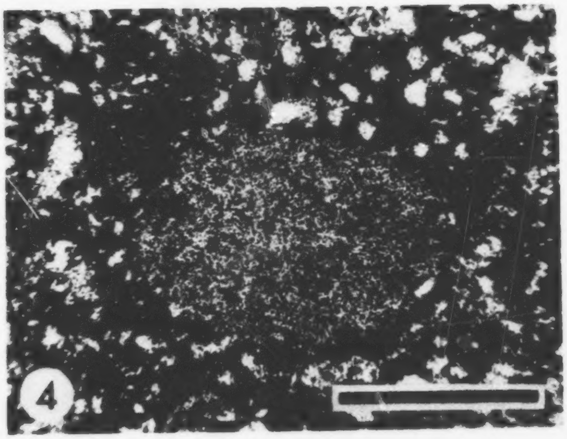
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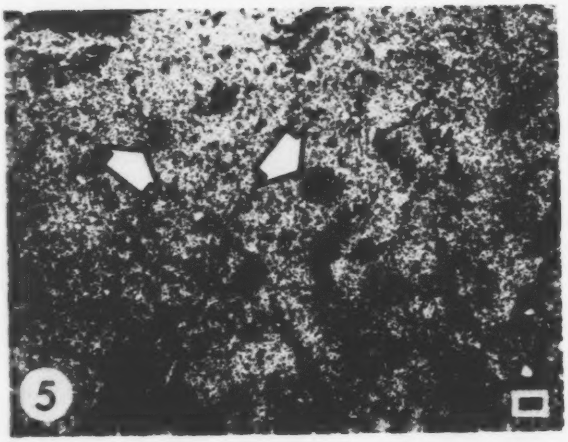
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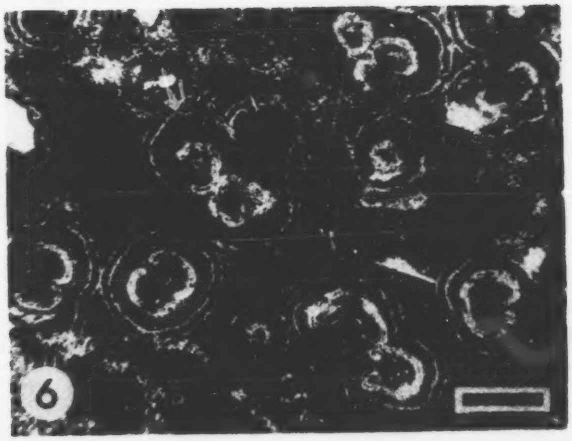
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Plate VI

(Horizontal scale on all figures is of length 1 cm)

Figure 1 — Pebble of redeposited, glauconitic sandstone, which originated as steinkern after costate pelecypod; Spinney Hill Sandstone, 702.6 m, Ceepee Daniels 6-29 (Lsd 6-29-31-19W3).

Figure 2 — Pebble of redeposited, glauconitic sandstone, incorporating pelecypod debris; other data as in Fig. 1.

Figure 3 — Pebble of cross-laminated, glauconitic sandstone; other data as in Fig. 1.

Figure 4 — Detail from surface of bored cobble of phosphatized wood in reworked, relict conglomeratic layer; base of Viking Formation, 645.3 m, Ceepee Dukesbury 13-18 (Lsd 13-18-34-21W3).

Figure 5 — Detail from surface of pebble of banded chert with brown-black patina and crescentic chatter marks; Viking Formation, 709.6 m, Canus Amoco Ulster Teo 6-2-29-24 (Lsd 6-2-29-24W3).

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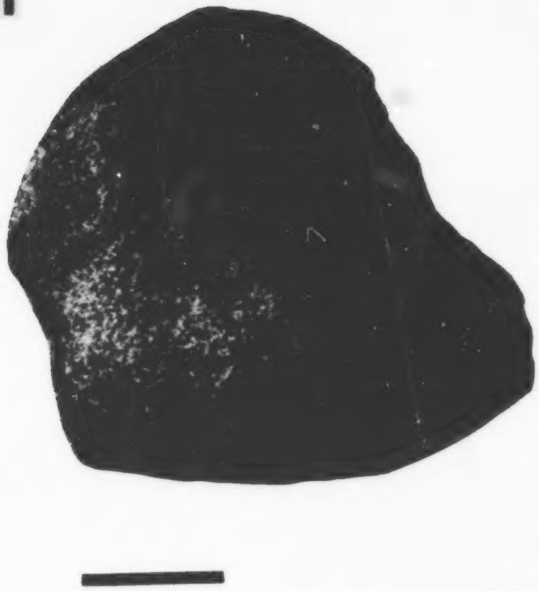

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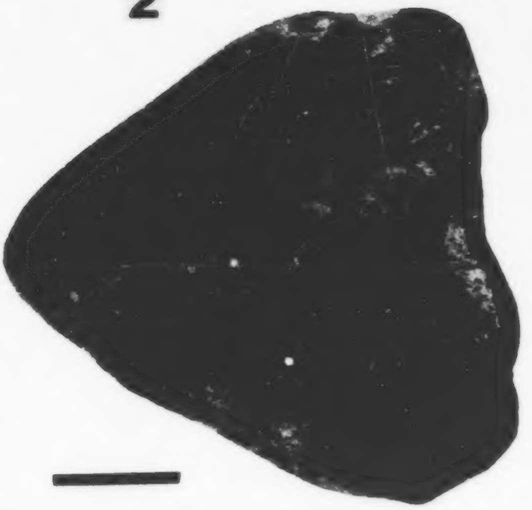

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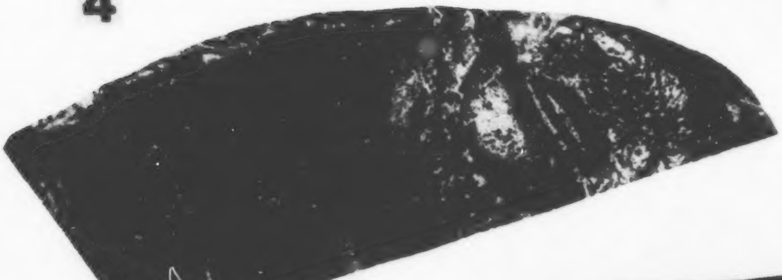

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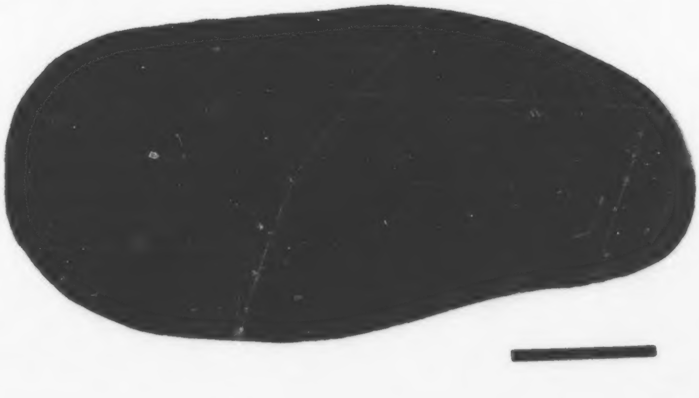

Plate VII

(Horizontal scale on all figures is of length 1 cm)

Figure 1 — Lenticular bedding preserved in siderite-rich concretionary layer; Viking Formation, 714.9 m, Phillips Husky Grattle 11-18 (Lsd 11-18-30-28W3).

Figure 2 — Ripple with internal laminae of unidirectional inclination truncated on left side by laminae of opposite inclination; Viking Formation, 630.8 m, Cdn-Sup Alminex Lacadena 6-21-23-16 (Lsd 6-21-23-16W3).

Figure 3 — Wavy bedding; Viking Formation, 668 m, Sarcee Canpet Beaufield 10-32 (Lsd 10-32-32-22W3).

Figure 4 — Wavy bedding; Viking Formation, 675.4 m, Altair et al Dodsland 11-25-31-22 (Lsd 11-25-31-22W3).

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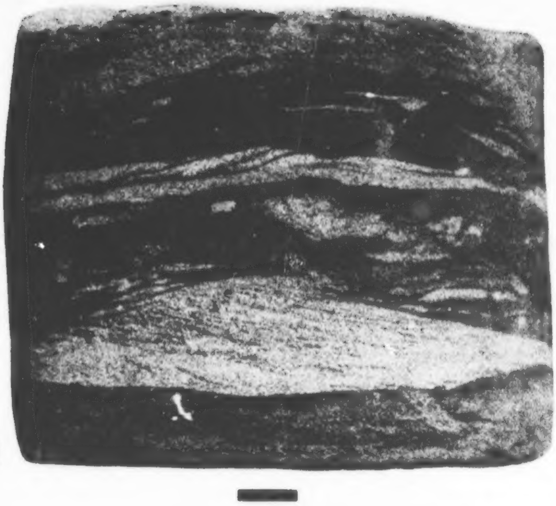

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Plate VIII

(Horizontal scale on all figures is of length 1 cm)

Figure 1 — Coset of tabular cross-laminae bounded by erosional interfaces; *Spirophyton* developed subparallel to lamination; Viking Formation, 723.4 m, Imperial Highbury 10-35-25-26 (Lsd 10-35-25-26W3).

Figure 2 — Ripple-drift cross-lamination resting upon sinusoidal laminae; coset bounded by burrows of *Spirophyton* type in muddy sandstone; Viking Formation, 724.1 m, Imperial Highbury 10-35-25-26 (Lsd 10-35-25-26W3).

Figure 3 — Composite sandstone layer made up of superposed sets of trough cross-laminae with successive sets of differing composition; note truncated mudstone layer; Joli Fou Formation, 682.4 m, Ceepee Dukesbury 13-18 (Lsd 13-18-34-21W3).

Figure 4 — Trough cross-lamination in composite sandstone layer; Joli Fou Formation, 680.9 m, Ceepee Dukesbury 13-18 (Lsd 13-18-34-21W3).

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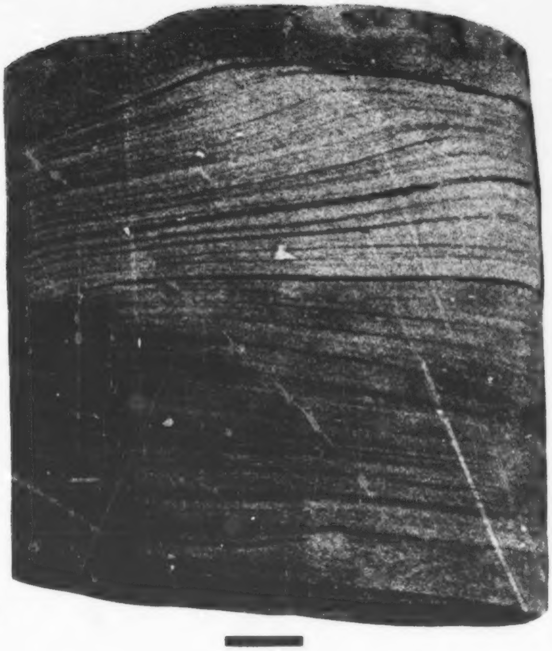

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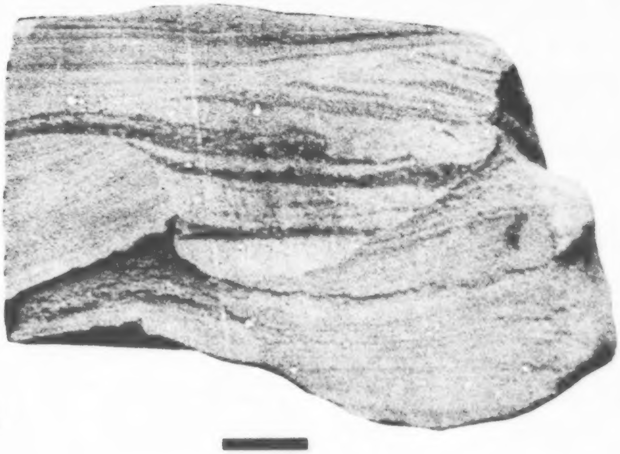

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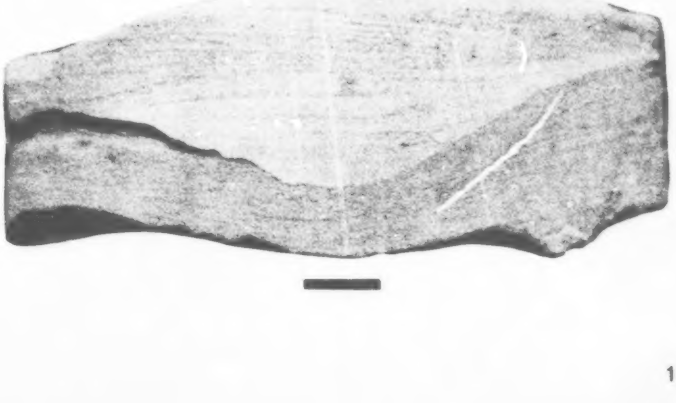

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Plate IX

(Figures are negative photographs of thin sections; horizontal scale is of length 1 mm)

Figure 1 — Small-scale cross-stratification in very fine-grained sandstone; St. Walburg Sandstone, 344.4 m, Cdn Seaboard Turtle L 4-16-55-18 (Lsd 4-16-55-18W3).

Figure 2 — Small-scale cross-stratification and pseudo-imbrication of prismatic debris of *Inoceramus* in pelecypod-foram biosparite layer; contact between layer and underlying bituminous mudstone is erosional; Second White-Speckled Shale, 105 m, D.N.R. Flotten Lake No. 2 (Lsd 4-10-65-17W3).

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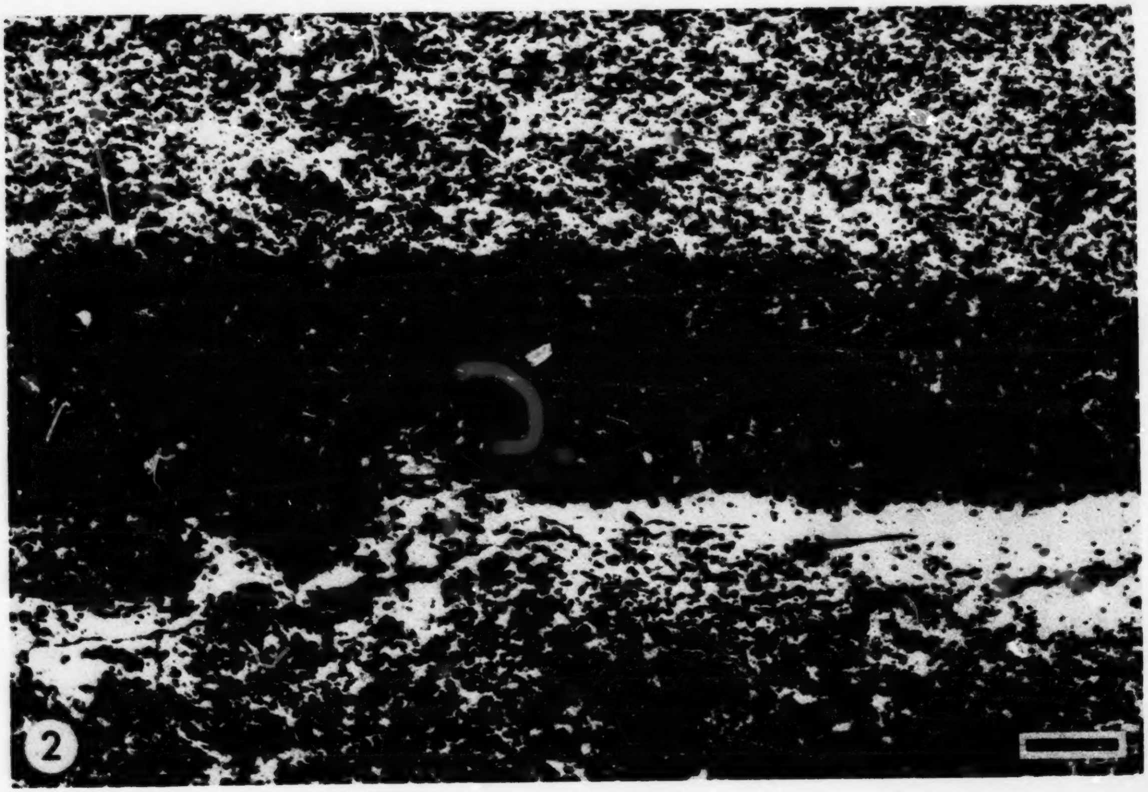

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Plate X

(Horizontal scale on all figures is of length 1 cm)

Figure 1 — Horizontal and gently inclined laminae in graded sandstone and coarse siltstone layers passing upward into mudstone; Pense Formation, 556.9 m, Goldfield Grt Cdn Dundurn 10-7-32-5 (Lsd 10-7-32-5W3).

Figure 2 — Horizontal and gently inclined lamination in conglomeratic sandstone; Viking Formation, 711.9 m, Oliphant NWRCo Gorefield 4-6-25-26 (Lsd 4-6-25-26W3).

Figure 3 — Laminar aggregate of pebbles and granules in mudstone; Joli Fou Formation, 724.1 m, Stanolind Imperial Beaufield No. C-1 (Lsd 1-21-33-25W3).

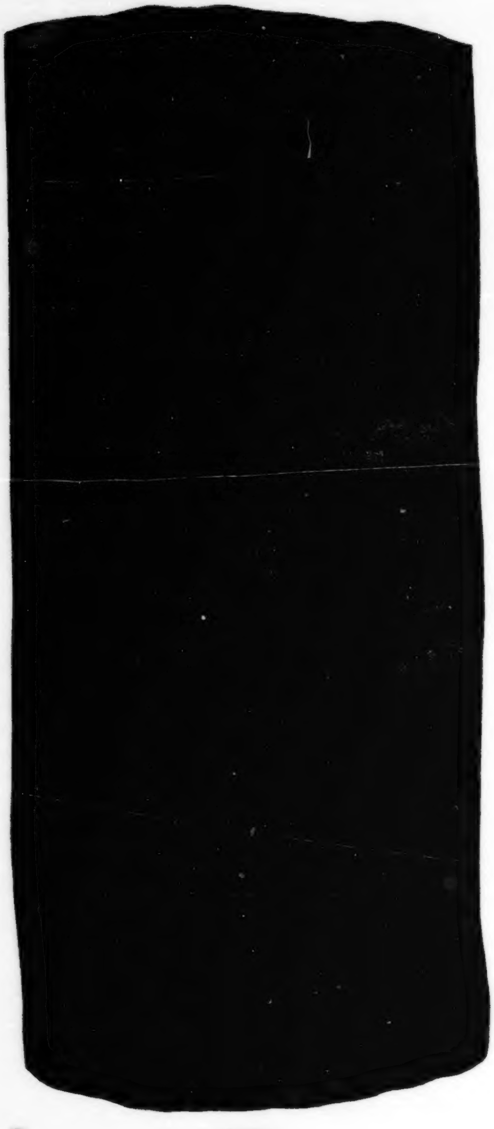

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Plate XI

(Horizontal scale on all figures is of length 1 cm)

Figure 1 — Sole of composite sandstone layer shown in Plate VIII, Fig. 4; short groove moulds have fragments of pelecypod valves at downcurrent ends.

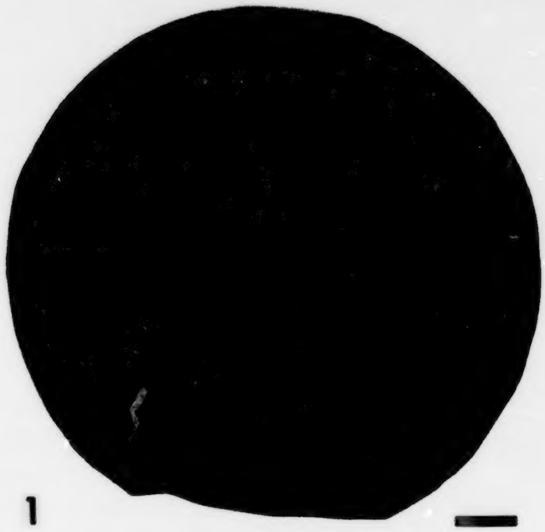
Figure 2 — Groove and prod moulds on sole of fine-grained sandstone layer; perforations of sole are mud-filled burrows of *Chondrites* type; Spinney Hill Sandstone, 763.2 m, Imperial Netherhill 11-17-27-21 (Lsd 11-17-27-21W3).

Figure 3 — Groove moulds on fine-grained sandstone sole transected by mud and sand-filled burrows; Spinney Hill Sandstone, 765 m, Imperial Netherhill 11-17-27-21 (Lsd 11-17-27-21W3).

Figure 4 — Scour-modified groove marks on sole of fine-grained sandstone layer; pelecypod debris concentrated in burrow; Spinney Hill Sandstone, 766 m, Imperial Netherhill 11-17-27-21 (Lsd 11-17-27-21W3).

Figure 5 — Groove and prod moulds on sole of fine-grained sandstone layer; fine pelecypod debris concentrated at erosional interface; Spinney Hill Sandstone, 762.9 m, Imperial Netherhill 11-17-27-21 (Lsd 11-17-27-21W3).

Figure 6 — Explanation as for Fig. 5; Spinney Hill Sandstone, 680.6 m, Ceepee Dukesbury 13-18 (Lsd 13-18-34-21W3).



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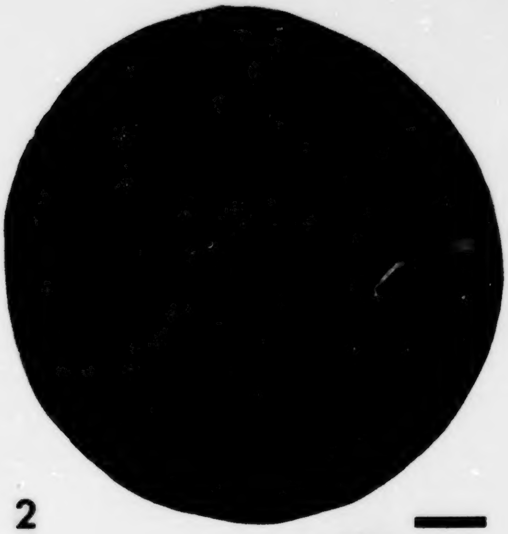

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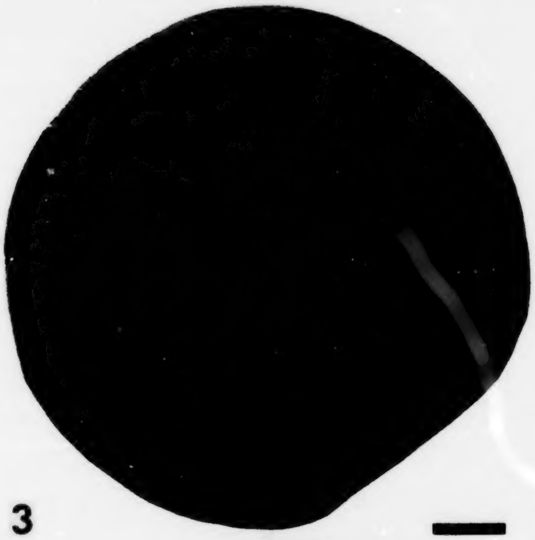

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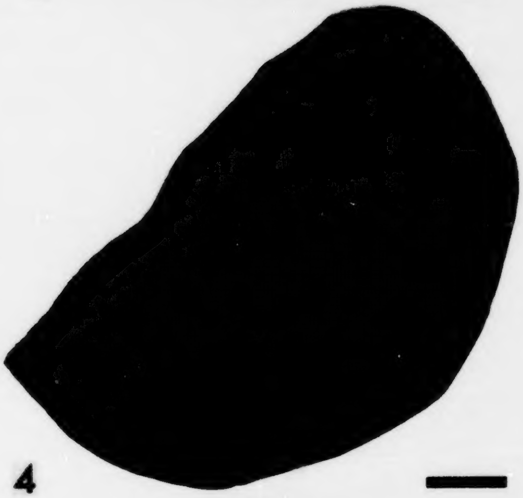

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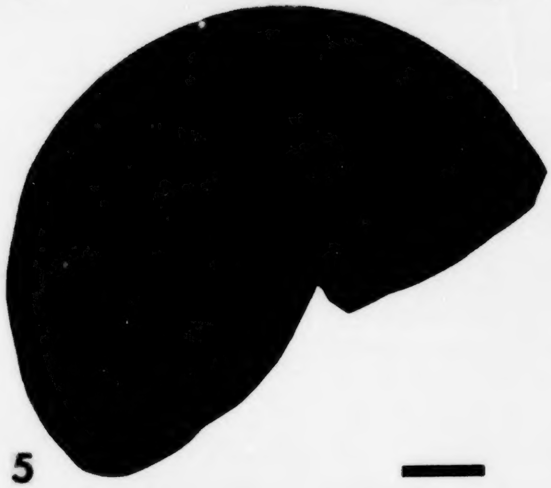

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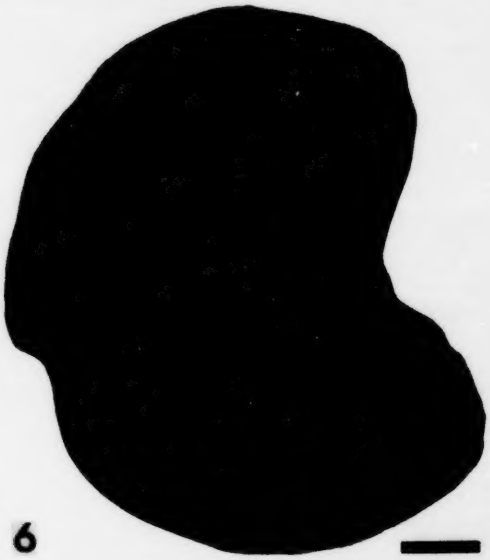

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Plate XII

(Horizontal scale on all figures is of length 1 cm)

Figure 1 — Sole of composite layer shown in Plate VIII, Fig. 3; note pelecypod debris in elongate scour mark.

Figure 2 — Sole of fine-grained sandstone layer showing elongate scour mark with pelecypod debris at base and scour-modified groove marks in walls; Spinney Hill Sandstone, 680.6 m, Ceepee Dukesbury 13-18 (Lsd 13-18-34-21W3).

Figure 3 — Vertical cross-section normal to current direction, in fine-grained sandstone layer shown in Fig. 2; note fill of horizontal laminae.

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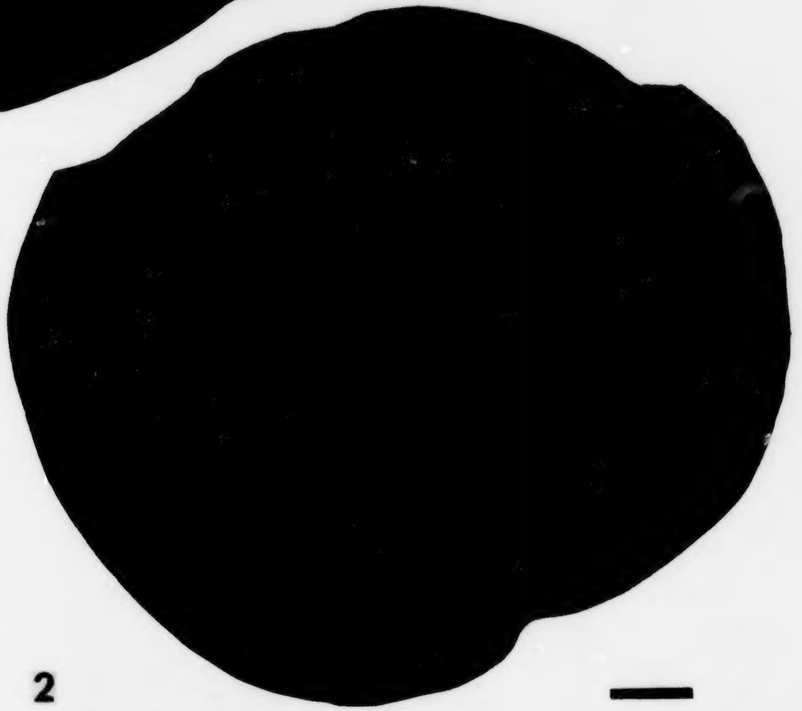

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Plate XIII

(Horizontal scale on all figures is of length 1 cm)

Figure 1 — Recumbent fold in fine-grained sandstone; note undisturbed laminae above and below folded layer; Viking Formation, 712.5 m, Canus Amoco Ulster Teo 6-2-29-24 (Lsd 6-2-29-24W3).

Figure 2 — Recumbent folds and shredded layers; Viking Formation, 710.6 m, Imperial Centrefield 13-10-26-21 (Lsd 13-10-26-21W3).

Figure 3 — Dike of Mannville siltstone transecting sideritic silty mudstone and incorporated pebbly sandstone at Mannville/Joli Fou contact; 517.9 m, Ibstone No. 3 (Lsd 11-31-48-27W3).

Figure 4 — Sole of fine-grained, shelly sandstone layer showing intersection by dike of fine-grained sandstone; Spinney Hill Sandstone, 708.4 m, Canpet Braeburn 10-9 (Lsd 10-9-31-20W3).

Figure 5 — Sand-filled cracks in mudstone; Viking Formation, 713.2 m, B. A. Jucknicss 13-15 (Lsd 13-15-22-23W3).

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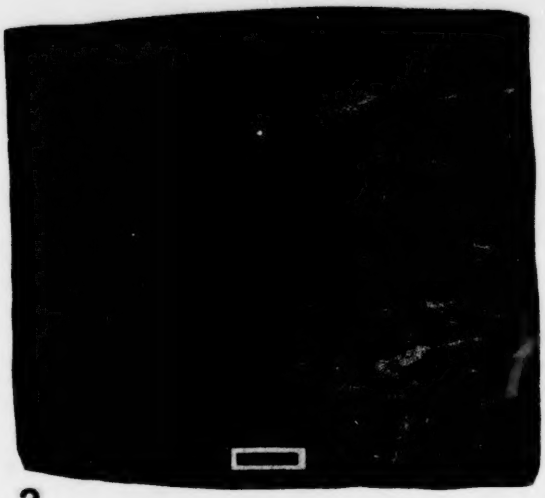

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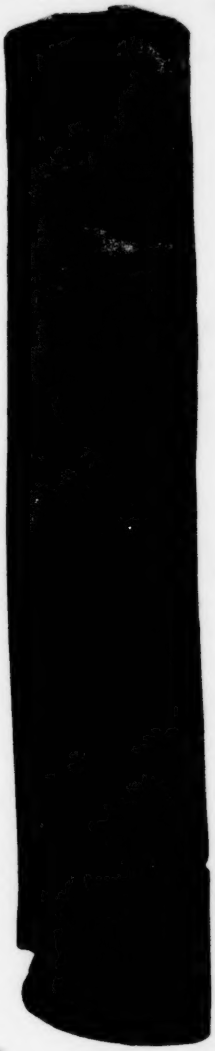

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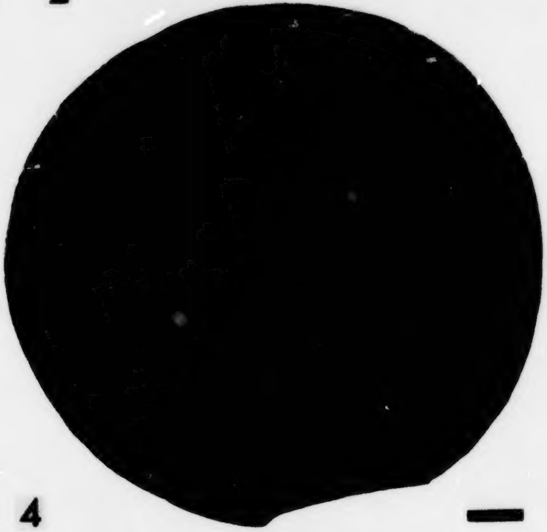

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Plate XIV

(Horizontal scale on all figures is of length 1 cm)

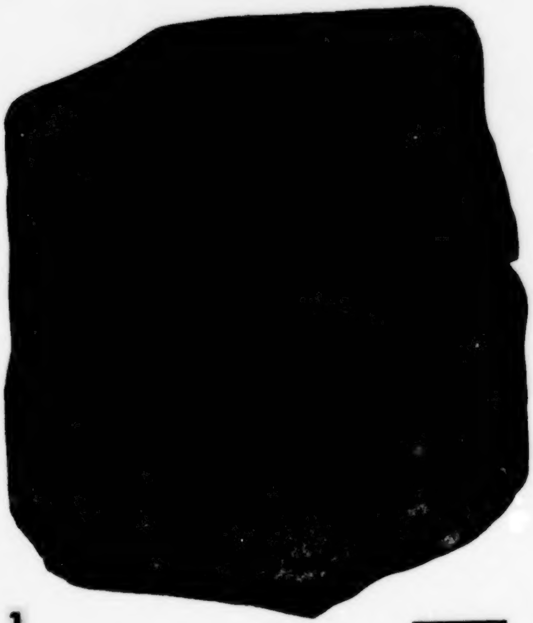
Figure 1 — Flakes of redeposited Mannville sediment and chert pebbles in basal Colorado conglomerate; oil-staining in dark areas; Joli Fou Formation, 525.6 m, Imperial HB Furness No. 1 (Lsd 8-7-48-27W3).

Figure 2 — Flakes of coccolith biomicrite concentrated in layers separated by dark bituminous mudstone; note difference in size of flakes belonging to successive layers; Second White-Speckled Shale, 374 m, Duval Saskatoon 6-18-36-6 (Lsd 6-18-36-6W3).

Figure 3 — Mud-filled *Teichichnus* system in cross-laminated bentonite, seen in elevation; Viking Formation, 733.3 m, Husky Dome Whiteside 1-15 (Lsd 1-15-30-26W3).

Figure 4 — Plan view of specimen shown in Fig. 3.

Figure 5 — Nodular pyrite bodies in bentonite layer; Viking Formation, 603.5 m, Cdn Sup Alminex Sanctuary 6-31-23-15 (Lsd 6-31-23-15W3).



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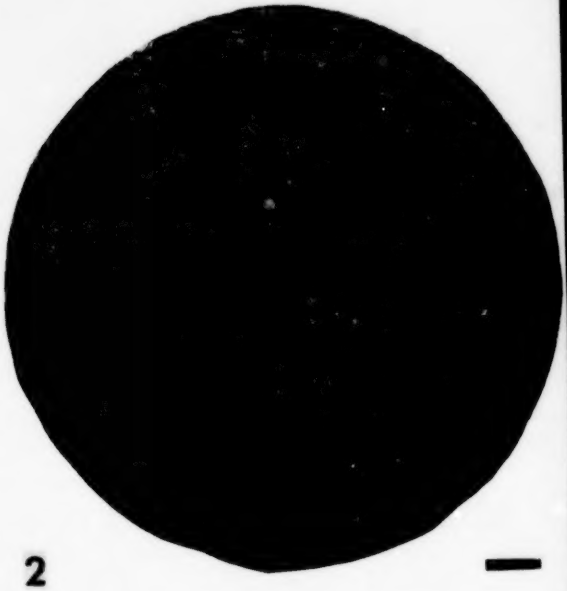

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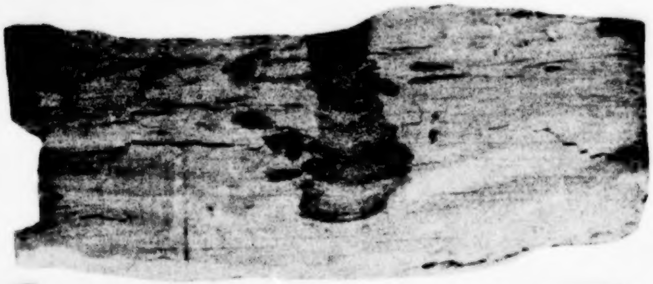

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Plate XV

(Horizontal scale on all figures is 1 cm)

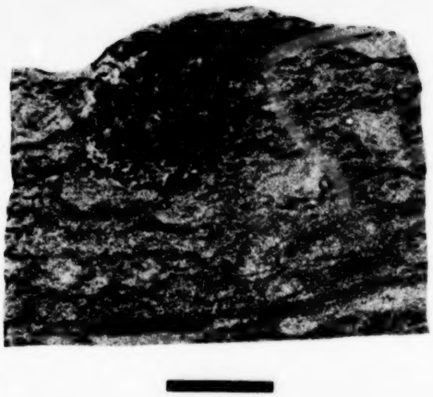
Figure 1 — Coarse sand grains forming tubular burrow infilling in bioturbated fine-grained sandstone; Viking Formation, 704.4 m, Socony Sohio D'Arcy 28-1 (Lsd 1-28-28-19W3).

Figure 2 — Inclined lamination of biogenic origin in bioturbated fine-grained sandstone; Viking Formation, 682.9 m, Imperial Glidden 7-33-26-23 (Lsd 7-33-26-23W3).

Figures 3 and 4 — Serial vertical sections through *Teichichnus*, showing inclined lamination in set with concave-upward lower boundary surface; Viking Formation, 707.7 m, Imperial Roslyn 10-35 (Lsd 10-35-29-28W3).

Figure 5 — Mutually truncating relationship of biogenic sets of inclined laminae in bioturbated sandstone; Viking Formation, 702.3 m, Clark Col-Smi Driver 12-28-31-24 (Lsd 12-28-31-24W3).

Figure 6 — Biogenic inclined stratification with irregular mudstone-rich layers separating thicker sandy layers; Viking Formation, 739.9 m, Imperial Smiley 7-7V-31-25 (Lsd 7-7-31-25W3).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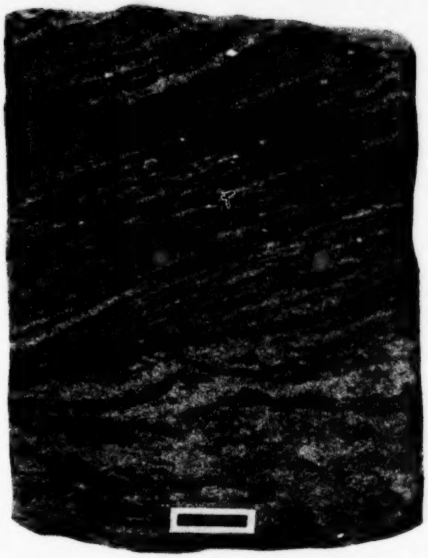
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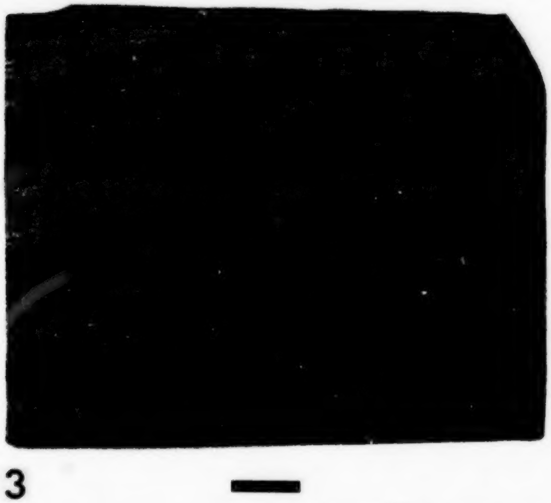
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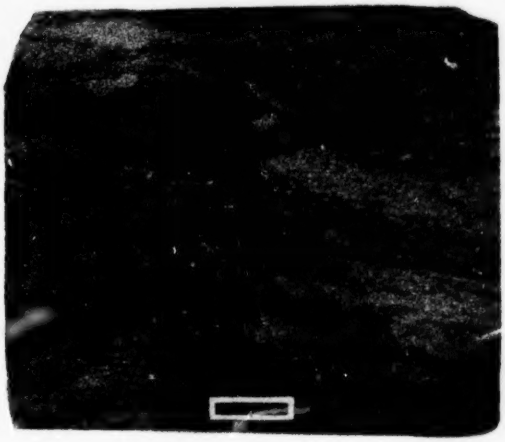
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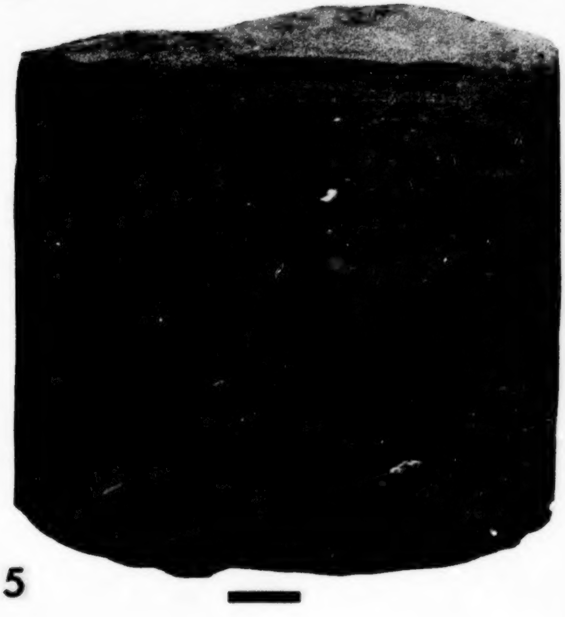
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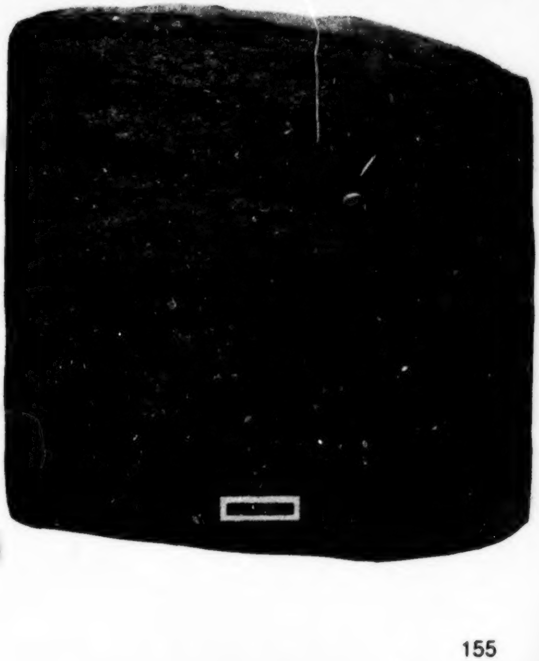
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Plate XVI

(Horizontal scale on all figures is of length 1 cm)

Figure 1 — Erosion surfaces in sideritic concretionary layer; note overfolds in siltstone layers; Big River Formation, 693.6 m, Imperial Marengo 11-21-29-27 (Lsd 11-21-29-27W3).

Figure 2 — Siderite-filled spherulites exhibiting central voids and replacement by pyrite in sideritic silty mudstone; Viking Formation, 744.2 m, Murphy et al Kindersley 7-19-28-21 (Lsd 7-19-28-21W3).

Figure 3 — Siderite-filled spherulites in sideritic silty mudstone; Viking Formation, 674.7 m, Socony Sohio Richlea 11-7 (Lsd 7-11-26-19W3).

Figure 4 — Siderite-filled spherulites concentrated in light-coloured core zone of concretionary sideritic silty mudstone layer; Viking Formation, 695.7 m, Imperial Marengo 11-21-29-27 (Lsd 11-21-29-27W3).

Figure 5 — Calcite concretions in calcite-cemented sandstone; Viking Formation, 696.2 m, Oliphant NWRCo Gorefield 4-2-25-27 (Lsd 4-2-25-27W3).

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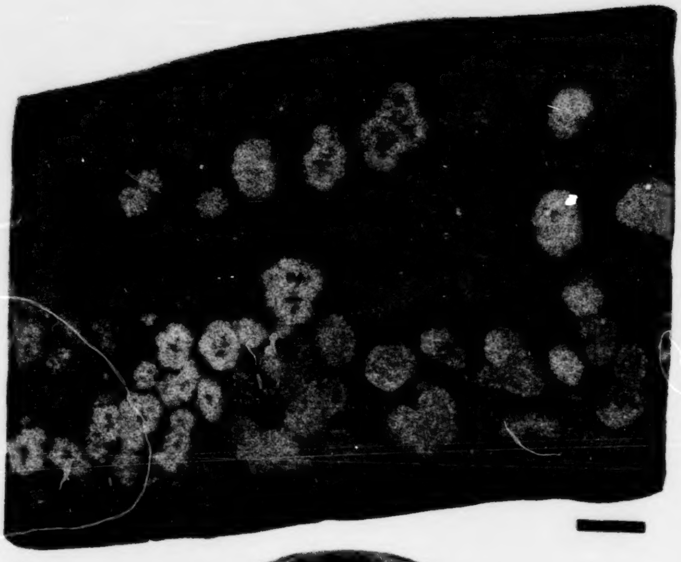

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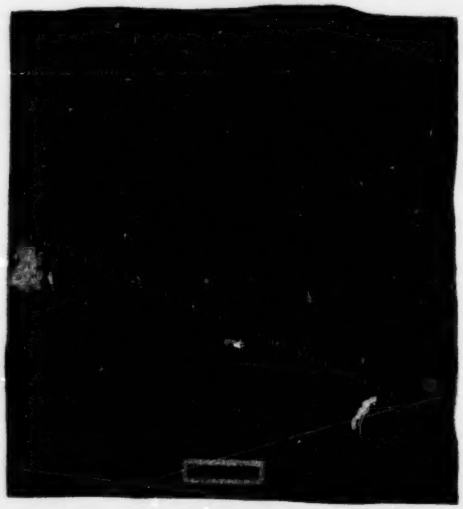

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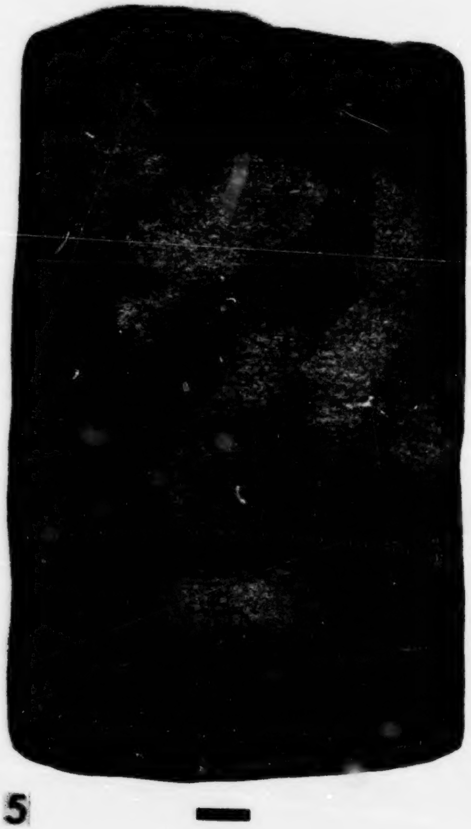

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Plate XVII

(Horizontal scale on all figures is of length 1 cm)

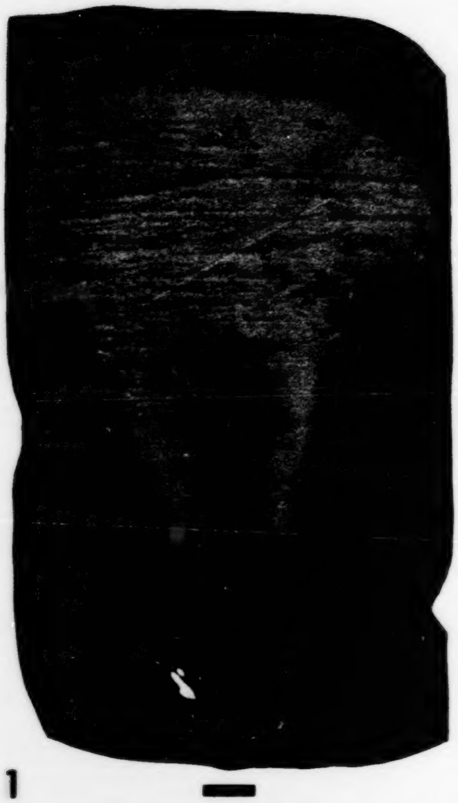
Figure 1 — Siderite-rich concretionary layer with downward distended base; Viking Formation, 645.6 m, Mosbacher CHCTV Cactus 10-11-36-26 (Lsd 10-11-36-26W3).

Figure 2 — Well indurated part of bioturbated muddy sandstone layer, incorporating coset of well-sorted sandy cross-laminae; Viking Formation, 745.1 m, Imperial Athenian 16-22-24-22 (Lsd 16-22-24-22W3).

Figure 3 — Intermittent stratiform pyrite development at erosional interfaces of fine-grained sandstone layer; Spinney Hill Sandstone, 820.5 m, Stanolind Prelate Crown 9-34 (Lsd 9-34-19-24W3).

Figure 4 — Explanation as for Fig. 3; Spinney Hill Sandstone, 762 m, Imperial Netherhill 11-17-27-21 (Lsd 11-17-27-21W3).

Figure 5 — Nodular pyrite concretion in fine-grained muddy sandstone; Viking Formation, 657.8 m, Williams Crk Greenan 11-2-26-17 (Lsd 11-2-26-17W3).



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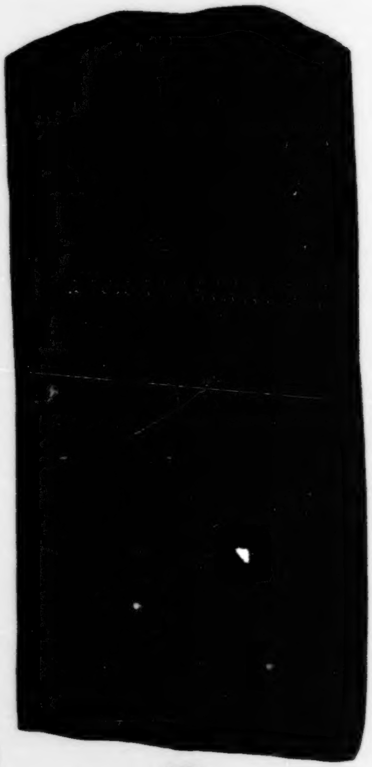

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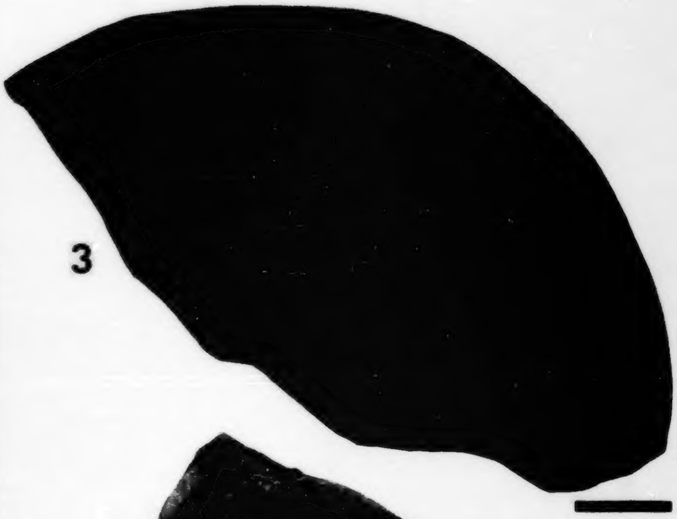

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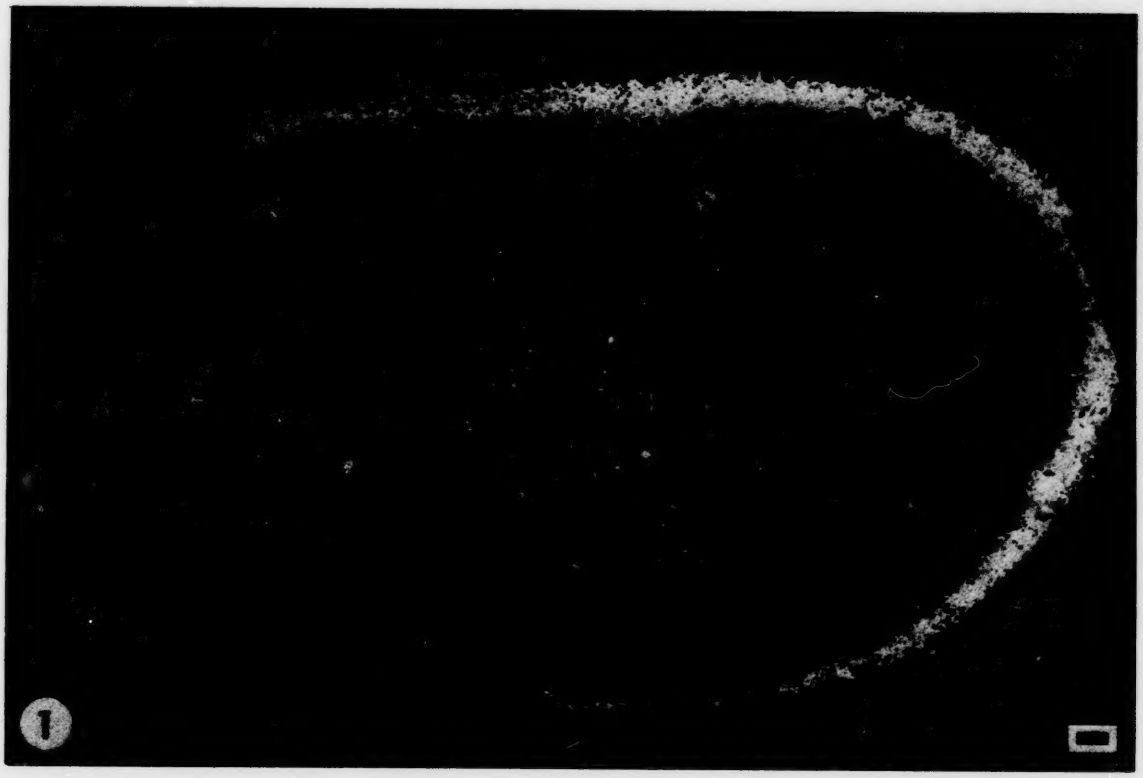
Plate XVIII

(Figures are negative photographs of thin sections; horizontal scale is of length 1 mm)

Figure 1 — Phosphatic nodule with random internal arrangement of floccules; for detail see Pl. V, Fig. 2; Joli Fou Formation, 621. 5 m, Ceepee Reward 4-28 (Lsd 4-28-38-24W3).

Figure 2 — Ripple-drift cross-lamination above erosion surface (arrow), phosphate nodule; for detail see Pl. V, Figs. 3 and 4; Joli Fou Formation, 463.4 m, Duval Saskatoon 6-18-36-6 (Lsd 6-18-36-6W3).



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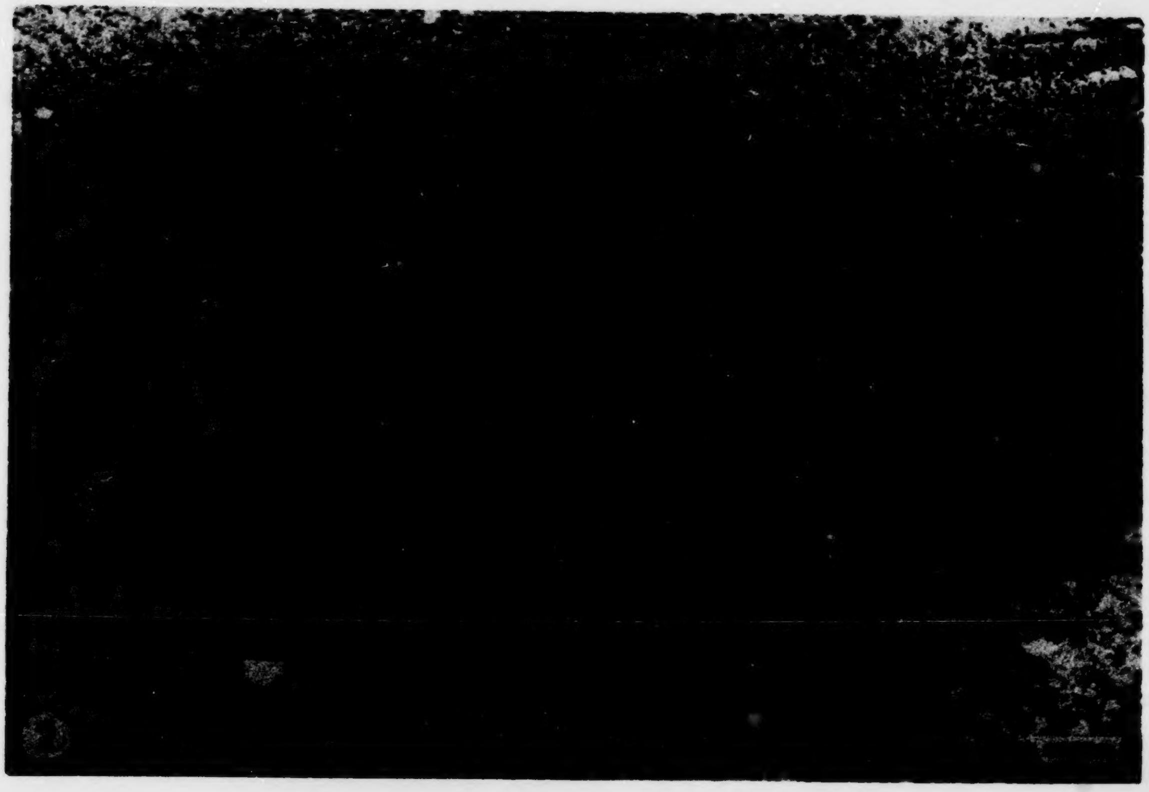


Plate XIX

(Horizontal scale on Figs. 1 to 4 inclusive and Fig. 6 is of length 1 cm and that on Fig. 5, 1 mm)

Figure 1 — Flattened mould of ammonite, probably *Watinoceras* sp.; rounded dark bodies are fish scales; part of a layer of white, coccolith-rich flakes also seen; Second White-Speckled Shale, 372.8 m, Duval Saskatoon 6-18-36-6 (Lsd 6-18-36-6W3).

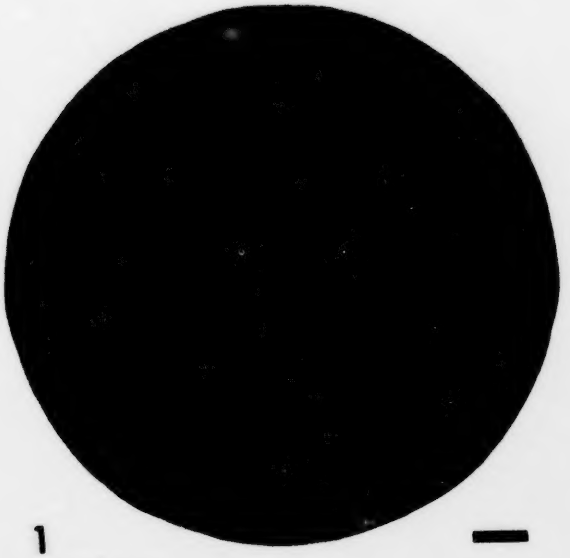
Figure 2 — Aboral side of ophiuroid preserved in fine-grained glauconitic sandstone with thin mudstone partings; Spinney Hill Sandstone, 693 m, Ceepee Daniels 6-29 (Lsd 6-29-31-19W3).

Figure 3 — Counterpart of specimen figured in 2 above.

Figure 4 — Oral side of ophiuroid preserved in fine-grained glauconitic sandstone with mudstone partings; Spinney Hill Sandstone, 693.1 m; other data as in Fig. 2.

Figure 5 — Detail from Fig. 4, showing oral plates.

Figure 6 — Coquinoidal layers made up of pelecypod debris in mudstone sequence and incorporated in sideritic concretion; Joli Fou Formation, 431.1 m, Mobil Celtic A6-30-51-23 (Lsd 6-30-51-23W3).



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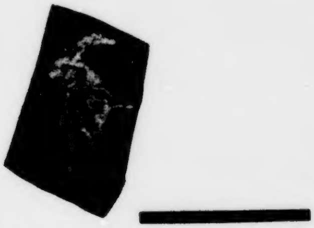

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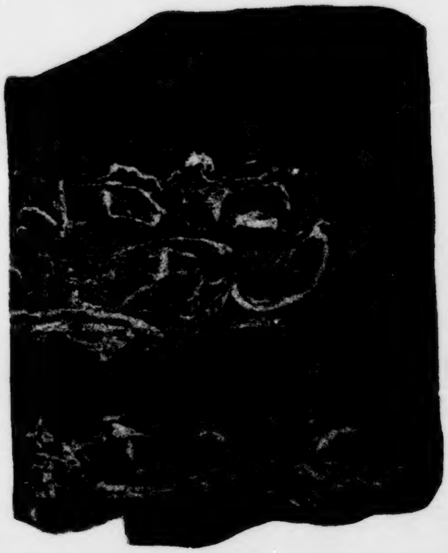

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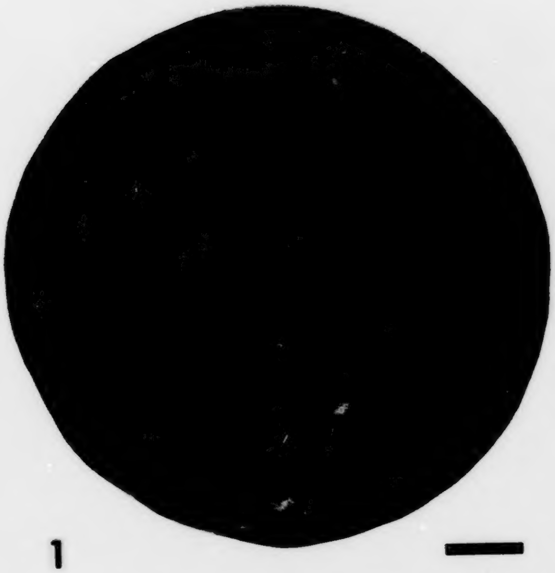
Plate XX

(Horizontal scale on all figures is of length 1 cm)

Figure 1 — Pelecypod debris concentrated at erosional interface below fine-grained sandstone layer; Spinney Hill Sandstone, 764.1 m, Imperial Netherhill 11-17-27-21 (Lsd 11-17-27-21W3).

Figure 2 — Edgewise coquina of pelecypod debris seen at upper surface of fine-grained sandstone layer; Spinney Hill Sandstone, 708.4 m, Canpet Braeburn 10-9 (Lsd 10-9-31-20W3).

Figure 3 — Edgewise coquina of pelecypod debris seen in vertical section; Spinney Hill Sandstone, 681.2 m, Ceepee Dukesbury 13-18 (Lsd 13-18-34-21W3).



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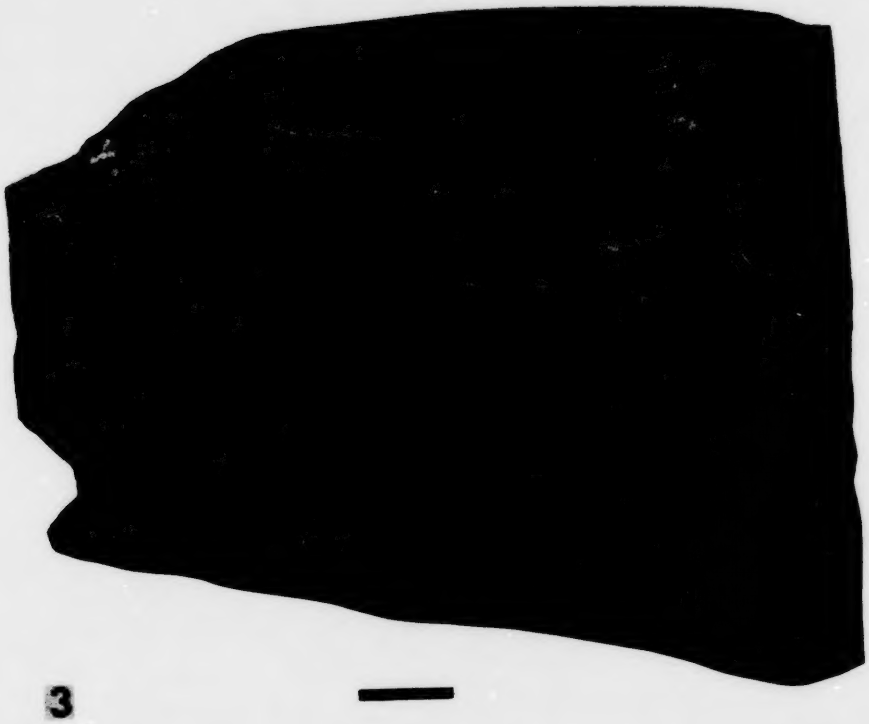

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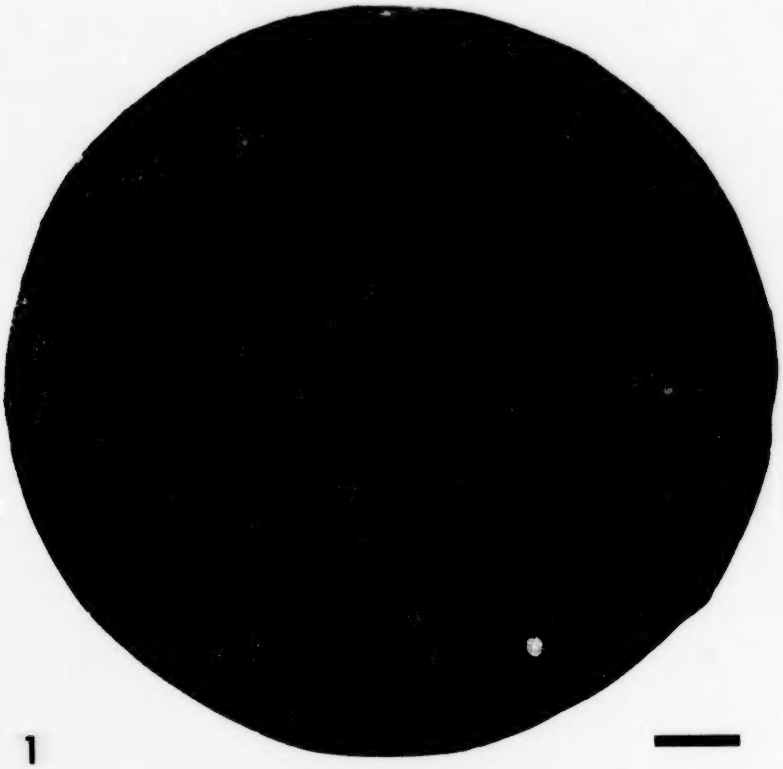
Plate XXI

(Horizontal scale on both figures is of length 1 cm)

Figure 1 — Laminar aggregate of fish skeletal debris; Big River Formation, 541.9 m, Marvel Kamalta Plato 14-7-25-17 (Lsd 14-7-25-17W3).

Figure 2 — Sole of fine-grained sandstone layer showing intersections of cross-laminae with depositional surface; lines of intersection defined by distribution of ostracode carapaces; Spinney Hill Sandstone, 762.9 m, Imperial Netherhill 11-17-27-21 (Lsd 11-17-27-21W3).



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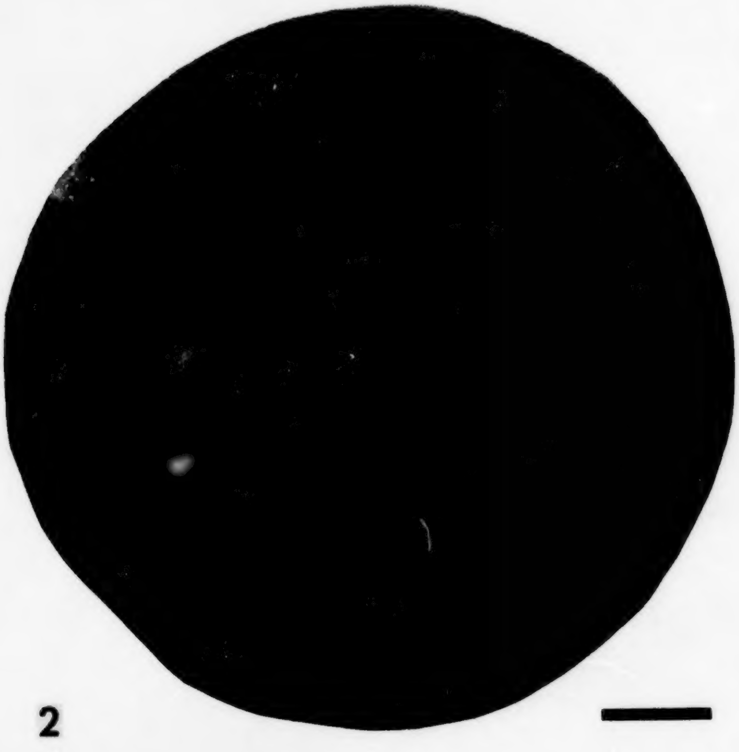

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Plate XXII

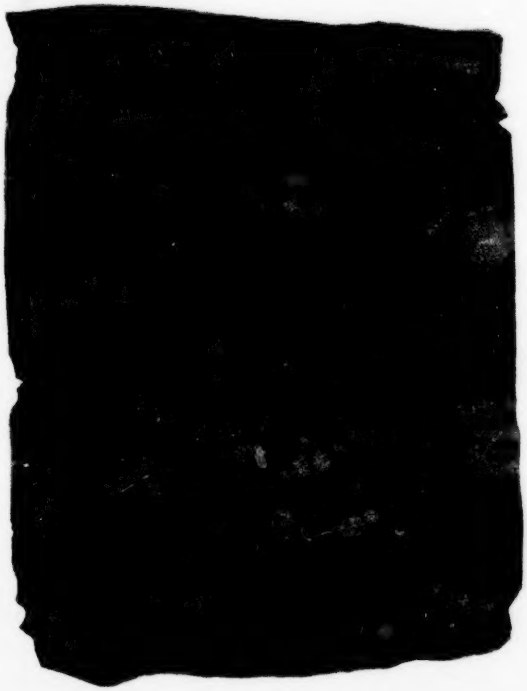
(Horizontal scale on all figures is of length 1 cm)

Figure 1 — Siderite-rich concretion incorporating cross-laminated, very fine-grained sandstone layer with eroded top characterized by extensive burrow development; Viking Formation, 716.1 m, Williamson Crown Avon 4-32-30-22 (Lsd 4-32-30-22W3).

Figure 2 — Fine pelecypod debris concentrated in burrows at sandstone sole; *Chondrites* well developed; Spinney Hill Sandstone, 764.4 m, Imperial Netherhill 11-17-27-21 (Lsd 11-17-27-21W3).

Figure 3 — Sand-filled tubular burrows of *Planolites* type at sandstone sole; Spinney Hill Sandstone, 762 m, Imperial Netherhill 11-17-27-21 (Lsd 11-17-27-21W3).

Figure 4 — Burrow similar to *Sagittichnus* containing shell debris, sole of fine-grained sandstone layer; Spinney Hill Sandstone, 819.9 m, Stanolind Prelate Crown No. 1 (Lsd 9-34-19-24W3).



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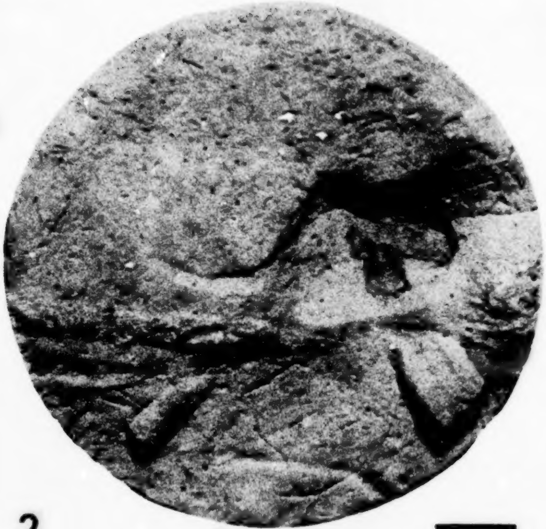

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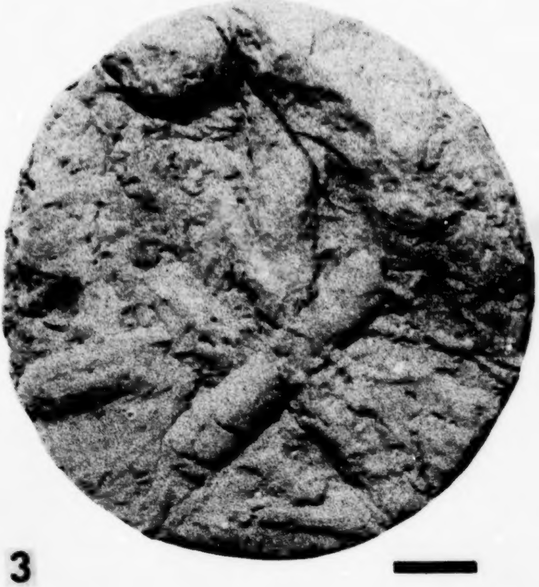

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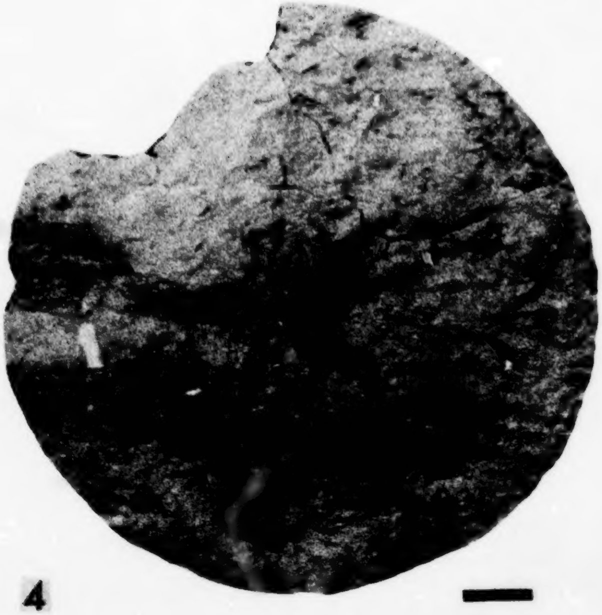

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Plate XXIII

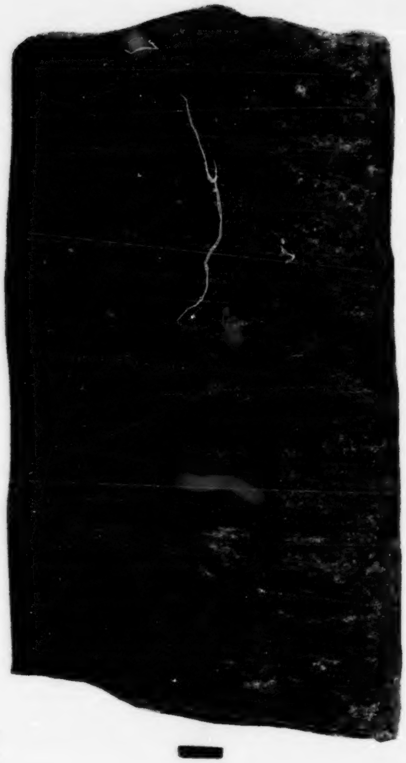
(Horizontal scale on all figures is of length 1 cm)

Figure 1 — *Teichichnus* in bioturbated fine-grained sandstone; Viking Formation, 748.3 m, Imperial Athenian 16-22-24-22 (Lsd 16-22-24-22W3).

Figure 2 — *Spirophyton* and *Teichichnus* in bioturbated fine-grained sandstone; Viking Formation, 712.5 m, Alminex Crystal 10-7-30-27 (Lsd 10-7-30-27W3).

Figure 3 — Alectorurid burrow; Viking Formation, 713.4 m, Imperial Smiley 15-5V-31-25 (Lsd 15-5-31-25W3).

Figure 4 — ? *Daedalus* ; Viking Formation, 712.5 m, Alminex Crystal 10-7-30-27 (Lsd 10-7-30-27W3).



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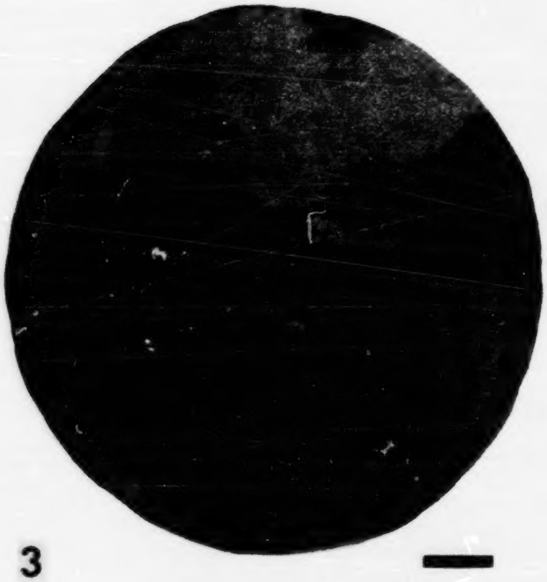

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Plate XXIV

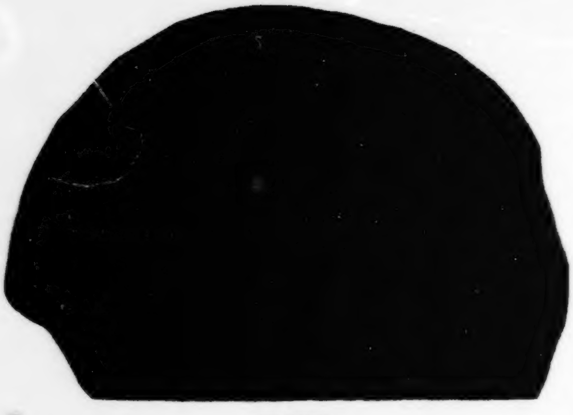
(Horizontal scale on all figures is of length 1 cm)

Figure 1 — Longitudinally striated, branching, sand-filled tubes, possibly of *Thalassinoides* in fine-grained sandstone with scattered coarse sand grains; Viking Formation, 684 m, Altair Clark G. E. Dods 6-14-31-22 (Lsd 6-14-31-22W3).

Figure 2 — Part of mud-filled vertical tube in fine-grained sandstone; Viking Formation, 738.8 m, Intercity Burstall No. 1 (Lsd 10-21-20-29W3).

Figure 3 — Sub-horizontal, mud-lined sand-filled tubes in fine-grained sandstone; Viking Formation, 672.7 m, Imperial Bayhurst 10-3V-24-25 (Lsd 10-3-24-25W3).

Figure 4 — Horizontal, mud-lined, sand-filled tubes in fine-grained sandstone; Viking Formation, 683.7 m, Dome Provo Lancer 10-9 (Lsd 10-9-22-21W3).



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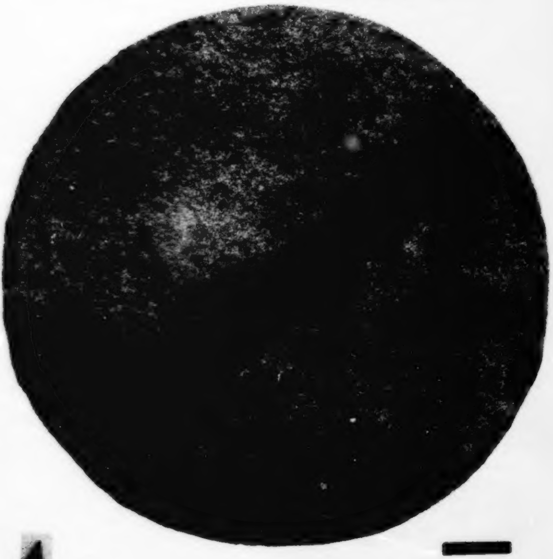

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Plate XXV

(Horizontal scale is of length 0.1 mm in Figs. 1 to 4 and 1 mm in Figs. 5 and 6; all figures show thin sections photographed in plane polarized light)

Figure 1 — Boring trace at periphery of phosphate nodule; arrow indicates dark (? manganese) layer below nodule surface; Viking Formation, 746.5 m, Kewanee Kindersley 11-29-29-25 (Lsd 11-29-29-25W3).

Figure 2 — Data as for Fig. 1.

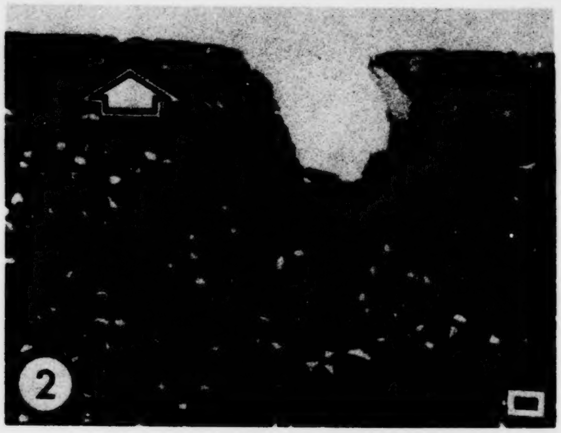
Figure 3 — Boring trace in phosphate nodule preserved as downward distension of dark (? manganese) layer near nodule surface (upper left arrow) into a pipe normal to the nodule periphery (lower left arrow), terminating in a void (right arrow); other data as in Fig. 1.

Figure 4 — Irregular cavity of biogenic origin with filling of fine sand and silt; phosphate nodule; other data as for Fig. 1.

Figure 5 — Smooth-walled boring with sand filling (arrow) in cobble of phosphatized wood, found in thin conglomerate layer; Viking Formation, 645.3 m, Ceepee Dukesbury 13-18 (Lsd 13-18-34-21W3).

Figure 6 — Data as for Fig. 5.

1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Appendix A — Depths of important horizons below Kelly Bushing.

A = Absent; E = Eroded; ND = Not Distinguished; NP = Not Penetrated.

Well Name	Location	KB (Feet above sea-level)	Depth of horizon below Kelly Bushing (feet)							
			Big River Top	St. Walburg Top	St. Walburg Base	Viking Top	Flotten Lake Top	Joli Fou Top	Spinney Hill Top	Mannville Top
Tidewater Craik Crown No. 2	4-29-25-1W3	2,063	1,808	A	A	2,113	A	2,131	2,155	2,280
Tidewater Allen Cr No. 16-11	16-11-33-1W3	1,748	1,391	A	A	1,621	A	1,643	1,675	1,743
Canpet et al Duck Lake 11-15	11-15-46-1W3	1,635	704	812	827	A	A	ND	973	1,052
Aberdeen No. 1	9-6-39-2W3	1,699	1,207	A	A	A	A	?1,446	1,503	1,623
Britalta North Cabin No. 1	16-26-47-2W3	1,652	670	A	A	A	A	A	949	1,035
HB Wildrose No. 1	12-14-50-2W3	1,671	543	A	A	A	A	? 770	796	905
PCA Saskatoon No. 10	4-4-37-3W3	1,782	1,301	A	A	1,523	A	1,541	1,600	1,713
HB Bridgeford 12-2-22-4	12-2-22-4W3	1,996	2,398	A	A	2,720	A	2,750	2,788	2,894
Hudson's Bay Elbow No. 1	1-34-23-4W3	1,777	2,100	A	A	2,410	A	2,426	2,464	2,575
Midas No. 1	4-2-36-4W3	1,722	1,503	A	A	1,723	A	1,745	1,811	1,927
California Standard Laird 16-16	16-16-43-4W3	1,722	1,104	A	A	A	A	?1,328	1,382	1,460
Tidewater Placid Hawarden Cr No. 1	12-10-29-5W3	2,014	2,204	A	A	2,465	A	2,487	2,520	2,622
Britalta Waldheim No. 1	2-20-42-5W3	1,779	1,237	A	A	A	A	?1,460	1,518	1,598
UHOL Parkside 8-3-48-5	8-3-48-5W3	1,682	717	A	A	A	A	? 950	976	1,090
CDR North Aquadell 13-12-20-6	13-12-20-6W3	2,012	2,465	A	A	2,799	A	2,830	2,887	2,990
Pan Am A1 West Saskatoon 14-10-35-7	14-10-35-7W3	1,725	1,381	A	A	1,637	A	1,658	1,709	1,810
Sohio No. 2 Stratigraphic Test	7-22-39-7W3	1,725	1,245	A	A	1,465	A	1,476	1,525	1,609
Ceja Ormeaux 13-33-52-7	13-33-52-7W3	1,735	E	602	660	A	A	? 712	728	845
Tidewater Birsay Crown No. 1	13-4-25-8W3	2,166	2,104	A	A	2,435	A	2,466	2,513	2,595
Philmac No. 12-11	12-11-38-8W3	1,648	1,146	A	A	1,402	A	1,412	1,458	1,545
Ceja Victoire 4-33-51-8	4-33-51-8W3	1,847	682	824	860	A	A	? 923	939	1,058
Swanson Crown No. 1	4-8-32-9W3	1,774	1,470	A	A	1,736	A	1,762	1,804	1,918
Freeport Sulphur Asquith 4-16	4-16-36-9W3	1,763	1,425	A	A	1,690	A	1,701	1,748	1,841

Canso Albercan Craigmore 13-4-44-9	13-4-44-9W3	1,980	1,619	A	A	A	A	?1,878	1,901	2,007
DNR Big River No. 5	2-22-58-9W3	1,585	E	A	A	E	A	A	400	431
Peyto GERC et al Lucky Lake 12-23-24-10	12-23-24-10W3	2,100	2,449	A	A	2,774	A	2,802	2,855	2,929
United Canadian Valentia No. 1	1-29-50-10W3	2,011	909	1,046	1,088	A	A	?1,156	1,173	1,296
Shell Otter Lk No. A4-31	4-31-55-10W3	1,957	643	791	836	A	872	885	950	980
Tidewater Beechy Cr. No. 1	1-29-23-11W3	2,411	2,291	A	A	2,647	A	2,673	2,721	2,816
Gulf Tidewater Cruse 13	13-18-29-11W3	1,904	1,612	A	A	1,904	A	1,939	1,981	2,073
Gulf Tidewater Watt No. 1	1-20-30-11W3	1,953	1,644	A	A	1,912	A	1,946	1,998	2,087
Liberal Speers 14-14-43-11	14-14-43-11W3	1,944	1,230	A	A	1,467	A	1,480	1,502	1,606
Dome Spiritwood No. 14-29	14-29-50-11W3	1,982	894	1,047	1,075	A	A	?1,140	1,158	1,286
Gulf Tidewater Hanson No. 16	16-11-35-12W3	1,844	1,478	A	A	1,743	A	1,759	1,802	1,896
Continental Maymont 13-11-42-12	13-11-42-12W3	1,826	1,185	A	A	A	A	?1,447	1,470	1,580
Tidewater Kyle Crown No. 1	3-32-21-13W3	2,665	2,403	A	A	2,779	A	2,812	2,867	2,955
TW Imp Forgan Cr 4-16-27-13	4-16-27-13W3	1,927	1,639	A	A	1,937	A	1,970	2,013	2,100
Gulf Tidewater Bents No. 12-27	12-27-33-13W3	1,979	1,613	A	A	1,881	A	1,905	1,953	2,039
Shell Rio Tinto Whitkow No. 2	14-34-47-13W3	2,394	1,465	1,622	1,641	A	A	?1,703	1,723	1,852
Albercan Crown 11-21	11-21-53-13W3	2,110	702	840	875	A	A	A	972	1,043
Tidewater Kyle Crown No. 5	13-20-21-14W3	2,271	1,993	A	A	2,366	A	2,414	2,481	NP
Cdn Sup Alminex Elrose 6-23-23-14	6-23-23-14W3	2,433	1,218	A	A	2,460	A	2,499	2,557	2,637
Tidewater Centre Crown No. 1	16-10-33-14W3	2,023	1,702	A	A	1,958	A	1,990	2,023	2,102
Heath Paige No. 1	16-3-40-14W3	2,391	1,780	A	A	A	A	?2,059	2,082	2,185
HB Jackfish Lake 12-3-46-14	12-3-46-14W3	1,939	1,204	A	A	A	A	?1,462	1,500	1,608
HB Thunderchild 6-23-54-14	6-23-54-14W3	1,958	723	850	882	A	954	965	1,026	1,058
Canadian Seaboard Divide No. 1	10-16-56-14W3	1,925	666	771	A	A	A	866	925	986
ZD Mobile Sask. Landing 4-11-20-15	4-11-20-15W3	2,159	2,227	A	A	2,412	A	2,470	2,533	2,617
Murphy Wilkie R/A B4-14-39-15	4-14-39-15W3	2,310	1,795	A	A	2,054	A	2,071	2,095	2,205
Texas Gulf Battleford R/A 13-31-44-15	13-31-44-15W3	1,863	1,153	A	A	A	A	?1,427	1,471	1,552

Appendix A — Depths of important horizons below Kelly Bushing. (Continued)

A = Absent; E = Eroded; ND = Not Distinguished; NP = Not Penetrated.

Well Name	Location	KB (Feet above sea-level)	Depth of horizon below Kelly Bushing (feet)							
			Big River Top	St. Walburg Top	St. Walburg Base	Viking Top	Flotten Lake Top	Joli Fou Top	Spinney Hill Top	Mannville Top
Nuco Cal-Stan Eckner 1-16-60-15	1-16-60-15W3	1,583	E	399	ND	A	ND	572	A	688
Cdn Sup Alminex Lacadena 6-21-23-16	6-21-23-16W3	2,047	1,715	A	A	2,054	A	2,108	2,173	2,253
Tidewater Herschel Crown No. 2	15-11-32-16W3	2,209	1,941	A	A	2,224	A	2,256	2,292	2,367
Liberal et al Palo 1-20-37-16	1-20-37-16W3	2,131	2,050	A	A	2,300	A	2,325	2,400	2,462
Murphy R/A Wilkie D16-19-39-16	16-19-39-16W3	2,264	1,782	A	A	2,032	A	2,056	2,080	2,197
Albercan Crown 10-7-52-16	10-7-52-16W3	2,238	1,146	1,285	1,311	A	A	1,406	A	1,505
Choqua et al Meadow Lake 5-1-59-16	5-1-59-16W3	1,624	E	314	ND	A	ND	? 479	A	582
Barnwell Herschel 16-28-30-17	16-28-30-17W3	2,076	1,828	A	A	2,104	A	2,141	2,185	2,258
Murphy Wilkie R/A A1-30-38-17	1-30-38-17W3	2,232	1,822	A	A	2,067	A	2,101	2,127	2,245
Canadian Seaboard Divide No. 2	7-14-56-17W3	2,351	1,070	1,182	1,244	A	1,267	1,328	A	1,434
Cdn Seaboard Divide Slimhole 1-26	1-26-57-17W3	2,022	667	775	849	A	865	925	A	1,029
MLO No. 1	16-36-58-17W3	1,584	E	284	359	A	376	448	A	569
Imperial Barnes 1-33-61-17	1-33-61-17W3	1,544	283	401	509	A	557	591	A	699
Tidewater Abbey Crown No. 2	1-31-21-18W3	1,920	1,530	A	A	1,947	A	2,020	2,101	2,181
Barnwell Herschel 12-10-30-18	12-10-30-18W3	2,290	2,016	A	A	2,330	A	2,363	2,411	2,480
Murphy R/A Wilkie D16-10-38-18	13-11-38-18W3	2,185	1,694	A	A	1,945	A	1,970	2,015	2,125
Husky Prongua SH A1-6-43-18	1-6-43-18W3	2,099	1,452	A	A	1,711	A	1,730	1,783	1,852
Husky Prongua SH C16-24-43-18	16-24-43-18W3	1,803	1,140	A	A	1,411	A	1,425	1,473	1,544

Husky Longhope R/A C13-21-50-18	13-21-50-18W3	2,147	1,183	1,327	1,348	A	A	1,461	A	1,566
BA Gillespie 16-2	16-2-51-18W3	2,238	1,188	1,335	1,361	A	A	1,465	A	1,576
Cdn Seaboard Horsehead 8-28-56-18	8-28-56-18W3	2,318	1,052	1,168	1,237	A	1,263	1,323	A	1,429
Pinn et al Shackleton 7-17-20-19	7-17-20-19W3	2,175	1,855	A	A	2,212	A	2,330	2,418	2,499
ARCO Handel 13-24-36-19	13-24-36-19W3	2,213	1,724	A	A	1,982	A	2,010	2,061	2,160
Rio Prado Mervin 4-8	4-8-50-19W3	1,960	973	1,115	1,137	A	A	1,249	A	1,352
Husky Brightsand R/A A1-6-54-19	1-6-54-19W3	2,239	1,222	1,348	1,406	A	1,471	?1,517	A	1,625
ZD HB Petro Dy Brock 11-23-28-20	11-23-28-20W3	2,353	2,124	A	A	2,443	A	2,481	2,548	NP
Imperial Netherhill 10-13-29-20	10-13-29-20W3	2,364	2,071	A	A	2,381	A	2,417	2,470	2,548
ARCO Handel 6-22-36-20	6-22-36-20W3	2,201	1,721	A	A	1,987	A	2,016	2,076	2,154
Caldina Oils No. 1	7-32-41-20W3	2,153	1,488	A	A	1,743	A	1,763	1,823	1,885
Husky Edam D16-29-48-20	16-29-48-20W3	1,893	995	1,144	1,152	A	A	1,256	A	1,378
Husky Edam D16-20-49-20	16-20-49-20W3	1,952	1,165	1,317	1,326	A	A	1,426	A	1,554
Sun Horsehead A1-4	1-4-56-20W3	2,140	903	1,022	1,072	A	1,147	1,193	A	1,310
Jeff Lake et al N Makwa 11-31-58-20	11-31-58-20W3	1,701	510	629	680	A	787	814	A	927
Jeff Lake et al Loon River 7-26	7-26-59-20W3	1,707	611	715	812	A	878	907	A	1,037
Phillips Husky Owen	6-19-23-21W3	2,253	1,957	A	A	2,301	A	2,391	2,449	2,536
Phillips Husky Mildrea No. 1	10-29-27-21W3	2,366	2,075	A	A	2,373	A	2,426	2,502	2,587
Husky Phillips Newburg No. 2	10-11-28-21W3	2,331	2,053	A	A	2,345	A	2,400	2,468	2,553
Ceja Gulf et al Kerrobert 2-29-34-21	2-29-34-21W3	2,235	1,840	A	A	2,118	A	2,150	2,214	2,288
ARCO Handel 6-24-35-21	6-24-35-21W3	2,142	1,711	A	A	1,964	A	1,995	2,060	2,137
BA Buffalo Smith St 4-22-41-21	4-22-41-21W3	2,317	1,703	A	A	1,955	A	1,985	2,043	2,113
Husky Birling C13-32-47-21	13-32-47-21W3	1,829	972	A	A	A	A	1,216	A	1,345
Husky Spruce Lake R/A B4-6-53-21	4-6-53-21W3	1,987	956	1,069	1,131	A	1,245	1,269	A	1,383
Pan Western St. Walburg No. 1	14-31-55-21W3	2,230	991	1,110	1,174	A	1,245	1,288	A	1,402
CS et al Brightsand 11-13	11-13-56-21W3	2,040	799	910	966	A	1,049	1,089	A	1,204
Tidewater Meadow Lake Crown No. 4-34	4-34-58-21W3	1,844	821	932	979	A	1,088	1,114	A	1,224
CDR Bestville West 13-9-17-22	13-9-17-22W3	2,403	2,130	A	A	2,520	A	2,645	A	2,792

Appendix A — Depths of important horizons below Kelly Bushing. (Continued)

A = Absent; E = Eroded; ND = Not Distinguished; NP = Not Penetrated.

Well Name	Location	KB (Feet above sea-level)	Depth of horizon below Kelly Bushing (feet)							
			Big River Top	St. Walburg Top	St. Walburg Base	Viking Top	Flotten Lake Top	Joli Fou Top	Spinney Hill Top	Mannville Top
Imp Bostonia R/A 12-11-27-22	12-11-27-22W3	2,318	2,033	A	A	2,345	A	2,403	NP	NP
Superior Dodsland No. 4	16-10-33-22W3	2,245	1,915	A	A	2,177	A	2,218	2,288	2,368
Husky Birling SH C13-35-46-22	13-35-46-22W3	1,855	1,058	A	A	A	A	1,328	A	1,447
Socony Englishman R R/A B4-33-52-22	4-33-52-22W3	1,937	955	1,078	1,135	A	1,260	1,279	A	1,409
Mid-Western St. Walburg 10-15	10-15-54-22W3	2,176	1,000	1,115	1,172	A	1,276	1,318	A	1,432
Imperial Goodsoil 8-11	8-11-62-22W3	1,708	E	690	743	A	837	870	A	997
Banff Aquit B1 Muskeg 10-8-65-22	10-8-65-22W3	2,227	807	925	962	A	1,043	1,088	A	1,215
Phillips Husky Dome Tuscola No. 1	7-29-25-23W3	2,254	1,992	A	A	2,320	A	2,385	2,473	2,546
ZD HB Petro Dy Glidden 11-23-26-23	11-23-26-23W3	2,285	1,982	A	A	2,287	A	2,345	2,425	2,514
Pan Am Onward No. 14-15	14-15-32-23W3	2,346	2,070	A	A	2,361	A	2,405	2,478	2,547
Bata No. 27	16-11-39-23W3	1,989	1,419	A	A	1,675	A	1,704	1,783	1,839
Mobil Hillsdale C13-16-46-23	13-16-46-23W3	1,864	1,057	A	A	A	A	1,338	A	1,448
Socony Mobil Celtic R/A B4-34-51-23	4-34-51-23W3	1,923	908	1,035	1,078	A	A	1,209	A	1,340
Mobil Celtic C5-14-52-23	5-14-52-23W3	1,922	1,064	1,197	1,249	A	A	1,373	A	1,523
Socony Charlotte B12-26	12-26-53-23W3	2,040	1,027	1,150	1,208	A	1,300	1,334	A	1,481
Socony Glenbogie R/A B12-27	12-27-54-23W3	2,160	1,028	1,154	1,202	A	1,336	1,356	A	1,495
Mobil Makwa 5-26-58-23	5-26-58-23W3	1,797	676	789	847	A	940	963	A	1,083
Banff Aquit Muskeg 7-8-64-23	7-8-64-23W3	1,997	731	855	892	A	977	1,017	A	1,143
Norvanian Hi Nor Eatonia 11-6-25-24	11-6-25-24W3	2,327	2,038	A	A	2,337	A	2,410	2,502	2,573
Altair Harr Marsh Buffalo 2-5-32-24	2-5-32-24W3	2,223	1,908	A	A	2,173	A	2,218	2,292	2,345

HB Bata Denzil No. 4	16-6-39-24W3	2,268	1,741	A	A	1,996	A	2,023	2,105	2,161
BA Hillsdale R/A 13-22-45-24	13-22-45-24W3	2,120	1,357	A	A	1,611	A	1,630	A	1,753
Mobil Husky McLaren R/A A1-29-50-24	1-29-50-24W3	2,013	1,122	1,254	1,266	1,390	A	1,398	A	1,537
Husky McLaren R/A B4-4-51-24	4-4-51-24W3	2,133	1,238	1,375	1,394	A	A	1,518	A	1,664
Husky Sandall R/A B4-14-51-24	4-14-51-24W3	1,921	1,035	1,171	1,205	A	A	1,331	A	1,469
Mobil Celtic B4-24	4-24-52-24W3	2,143	1,141	1,275	1,317	A	1,442	1,469	A	1,598
Socony Red Cross R/A C13-23	13-23-54-24W3	2,075	1,050	1,183	1,222	A	1,361	1,379	A	1,506
Nor Am Jeff Peck Lake 6-16-56-24	6-16-56-24W3	2,043	975	1,104	1,126	A	1,253	1,274	A	1,413
Banff Aquit Bl 1971 Makwa 4-14-57-24	4-14-57-24W3	2,027	875	1,004	1,045	A	1,152	1,175	A	1,295
Aquit Beacon Hill 11-3-63-24	11-3-63-24W3	1,675	421	543	574	A	670	710	A	834
Aquit Beacon Hill 12-4-63-24	12-4-63-24W3	1,660	412	540	571	A	674	711	A	827
Mobil Muskeg River 4-16-66-24	4-16-66-24W3	2,038	700	819	854	A	937	968	A	1,100
Phillips Husky Quinney Well No. 1	7-29-24-25W3	2,227	1,938	A	A	2,222	A	2,332	A	2,498
Jeff Lake et al Smiley 14-27-31-25	14-27-31-25W3	2,314	1,957	A	A	2,246	A	2,290	A	2,415
HB-Can Southern Donegal 16-22-38-25	16-22-38-25W3	2,274	1,751	A	A	2,000	A	2,033	A	2,160
KR Triad Freemont A11-10-44-25	11-10-44-25W3	2,202	1,531	A	A	1,779	A	1,799	A	1,931
Husky McLaren A7-25-50-25	7-25-50-25W3	2,084	1,136	1,270	1,279	1,397	A	1,410	A	1,536
Husky Hillmond R/A B4-35	4-35-51-25W3	1,981	1,058	1,195	1,212	A	1,328	1,355	A	1,470
Imp Monnery River 13-11	13-11-54-25W3	2,099	1,056	1,189	1,220	A	1,335	1,354	A	1,489
Imp Porcupine 16-4-56-25	16-4-56-25W3	2,076	1,085	1,212	1,227	A	1,360	1,377	A	1,483
IOE Beacon Hill Opp 14-8-62-25	14-8-62-25W3	1,771	554	694	720	A	810	840	A	956
Imp Beacon Hill 8-16-62-25	8-16-62-25W3	1,751	485	623	646	A	746	774	A	883
Aquit Beacon Hill 1-22-62-25	1-22-62-25W3	1,736	490	616	645	A	766	795	A	906
Banff Aquit Beacon Hill 1-25-62-25	1-25-62-25W3	1,815	544	679	696	A	805	828	A	946

Appendix A — Depths of important horizons below Kelly Bushing. (Continued)

A = Absent; E = Eroded; ND = Not Distinguished; NP = Not Penetrated.

Well Name	Location	KB (Feet above sea-level)	Depth of horizon below Kelly Bushing (feet)							
			Big River Top	St. Walburg Top	St. Walburg Base	Viking Top	Flotten Lake Top	Joli Fou Top	Spinney Hill Top	Mannville Top
CS Primrose Lake 11-20-65-25	11-20-65-25W3	2,160	840	964	999	A	1,077	1,100	A	1,230
Sask DMR Primrose Lake 3-7-68-25	3-7-68-25W3	1,985	557	676	716	A	801	832	A	951
Westerham No. 1	4-12-23-26W3	2,156	1,954	A	A	2,255	A	2,369	A	2,540
Dungloe No. 1	8-35-23-26W3	2,266	1,958	A	A	2,254	A	2,351	A	2,525
Mich Wis CDR Flaxcombe 10-31-29-26	10-31-29-26W3	2,346	2,124	A	A	2,430	A	2,487	A	2,616
Dewer No. 1	8-29-30-26W3	2,304	2,065	A	A	2,350	A	2,397	A	2,528
Pennant Decalta Smiley 16-20-31-26	16-20-31-26W3	2,365	2,122	A	A	2,400	A	2,452	A	2,590
MOS CHCTV Heartshill R/A 4-35-36-26	4-35-36-26W3	2,275	1,850	A	A	2,120	A	2,151	A	2,281
B.A. EyeHill Partington 2-31-39-26	2-31-39-26W3	2,234	1,742	A	A	1,986	A	2,007	A	2,142
Francana Manito L R/A 13-8-43-26	13-8-43-26W3	2,127	1,515	A	A	1,770	A	1,789	A	1,913
Husky East Marshall 13-34-48-26	13-34-48-26W3	1,995	1,162	A	A	A	A	A	A	1,552
Aberfeldy Unit A14-30-49-26	14-30-49-26W3	2,005	1,157	A	A	1,402	A	1,416	A	1,555
Husky W. Landrose R/A B4-11-50-26	4-11-50-26W3	2,118	1,282	A	A	1,528	A	1,544	A	1,680
Husky N Landrose B7-23	7-23-50-26W3	2,017	1,124	1,263	1,275	A	1,375	1,401	A	1,509
Husky Greenstreet R/A C13-33	13-33-52-26W3	1,761	831	973	987	A	A	A	A	1,240
Husky Deer Creek R/A C13-2	13-7-53-26W3	1,897	915	1,054	1,079	A	1,199	1,212	A	1,335
Terrebonne Harlan R/A C13-10	13-10-53-26W3	1,283	972	1,110	1,136	A	A	A	A	1,386
Beverly Hills Petroleum No. 1	10-32-55-26W3	2,239	1,240	A	A	A	A	ND	A	1,653

Imp Pierceland 3-4-62-26	3-4-62-26W3	1,766	605	762	774	A	892	916	A	1,020
GAO Cold Lake 10-22-64-26	10-22-64-26W3	1,828	488	622	655	A	782	799	A	918
GAO Cox et al Cold Lake 10-14-65-26	10-14-65-26W3	2,008	711	843	870	A	977	998	A	1,111
Sask DMR Primrose Lake 9-7-68-26	9-7-68-26W3	2,000	501	615	650	A	754	781	A	898
Baysel et al Westerham 11-29-22-27	11-29-22-27W3	2,307	2,083	A	A	2,372	A	2,505	A	2,668
Oliphant Northwestern Gorefield 6-12-25-27	6-12-25-27W3	2,274	2,020	A	A	2,300	A	2,413	A	2,571
Allied Embassy Marengo 6-35-28-27	6-35-28-27W3	2,364	2,095	A	A	2,396	A	2,449	A	2,604
Phillips Norengo 12-2	12-2-29-27W3	2,335	2,067	A	A	2,359	A	2,408	A	2,561
CDR Marengo 6-25-29-27	6-25-29-27W3	2,300	2,027	A	A	2,308	A	2,370	A	2,500
Sarcee Barryville 7-31-35-27	7-31-35-27W3	2,264	2,203	A	A	2,456	A	2,500	A	2,629
Husky Cactus Lake R/A 4-36-36-27	4-36-36-27W3	2,264	1,854	A	A	2,110	A	2,145	A	2,277
KR Triad Reflex 1-29-42-27	1-29-42-27W3	2,165	1,591	A	A	1,853	A	1,872	A	1,997
Hub City No. 1	14-19-48-27W3	2,103	1,301	A	A	A	A	A	A	1,684
Husky Lloyd (2) D10-17-49-27	10-17-49-27W3	2,103	1,273	A	A	1,325	A	1,545	A	1,667
Husky Aberfeldy D15-23	15-23-49-27W3	2,020	1,187	A	A	A	1,431	1,448	A	1,565
Husky Northminster R/A B1-15	1-15-52-27W3	1,865	950	A	A	A	A	A	A	1,365
HB Frenchman Butte 6-16-55-27	6-16-55-27W3	2,175	1,119	A	A	A	A	ND	A	1,500
Imp Beaver River 14-23-60-27	14-23-60-27W3	1,877	760	A	A	A	A	A	A	1,172
Tenn Martineau 1-10-66-27	1-10-66-27W3	1,883	561	687	720	A	840	864	A	983
Sun Martineau 4-23-66-27	4-23-66-27W3	1,973	677	804	836	A	956	983	A	1,088
Mobil South Estuary 11-13	13-11-22-28W3	2,319	2,100	A	A	2,392	A	2,533	A	2,691
Alsask No. 1	10-7-28-28W3	2,253	1,969	A	A	2,260	A	ND	A	2,477
Husky Panama 4-9-35-28	4-9-35-28W3	2,320	2,000	A	A	2,278	A	2,317	A	2,449
Amerada Cr Reflex 1-21-42-28	1-21-42-28W3	2,015	1,467	A	A	1,723	A	1,741	A	1,865
Husky Epping A16-11	16-11-47-28W3	2,077	1,299	A	A	A	A	A	A	1,687
Nuco Acroil D14-24	14-24-48-28W3	2,121	1,315	A	A	1,557	A	1,578	A	1,711
Inter City Burstall No. 2	1-1-21-29W3	2,388	2,173	A	A	2,469	A	2,645	A	2,778
Texcan Alsask 16-22-27-29	16-22-27-29W3	2,297	2,036	A	A	2,338	A	2,393	A	2,551